Observations of the Surge-Type Black Rapids Glacier, Alaska, During a Quiescent Period, 1970-92

By Thomas A. Heinrichs, Lawrence R. Mayo, Dennis C. Trabant, *and* Rod S. March

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To Obtain
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
meter per second (m/s)	3.281	foot per second
meter per year (m/yr)	3.281	foot per year
gram (g)	0.03527	ounce
degreee Celsius (°C)	F = 1.8 x °C + 32	degree Fahrenheit (°F)

Other abbreviations in this report:

g/cm^3, gram per cubic centimeter
m_{we}, meter water equivalent

Sea level:

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929), a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Observations of the Surge-Type Black Rapids Glacier, Alaska, During a Quiescent Period, 1970-92

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Abstract

This report presents 23 years (1970 to 1992) of observations of Black Rapids Glacier, Alaska. Black Rapids Glacier is a surge-type glacier which most recently surged in 1936-37 and is currently in its quiescent phase. This glacier is of special interest because it is a potential hazard to the trans-Alaska oil pipeline. Ten sites on the glacier were monitored from 1972 to 1987, and three sites were monitored from 1988 to 1992. The measurement program presented here includes observations of surface mass balance, ice velocity, and surface altitude made twice each year. Additional one-time data include observations of ice thickness, previously unreported observations of the 1936-37 surge, establishment of the geodetic control monuments, and a new map of Black Rapids Glacier.

INTRODUCTION

Black Rapids Glacier—A Surge-Type Glacier

A surge-type glacier lies relatively quiescent for decades, growing steeper and accumulating mass in its reservoir area for its next brief period of surge motion (Meier and Post, 1969). During a surge, the built-up mass is transported at speeds of up to 100 times normal flow rates down-glacier, resulting in thickening low on the glacier in the surge receiving area and, sometimes, a terminus advance. Although considerable effort has gone into studies of a few surge-type glaciers, many basic questions about the nature of surge-type glaciers remain unanswered. For example, why do some glaciers surge while other nearby glaciers do not? What triggers a surge? Why are surge-type glaciers geographically clustered in only a few well-defined areas? (Post, 1969). Long-term observations of surge-type glaciers during their quiescent phases with simultaneous observations of non-surge-type glaciers make possible the understanding of this interesting phenomenon.

This report presents a long-term data set gathered during the quiescent phase of a surge-type glacier: Black Rapids Glacier in the Alaska Range. This glacier most recently surged in 1936-37. A regular series of deformed (looped) moraines on the glacier indicate that the glacier surged three or more times during the 30-km-long transit of ice from its equilibrium line to its terminus.

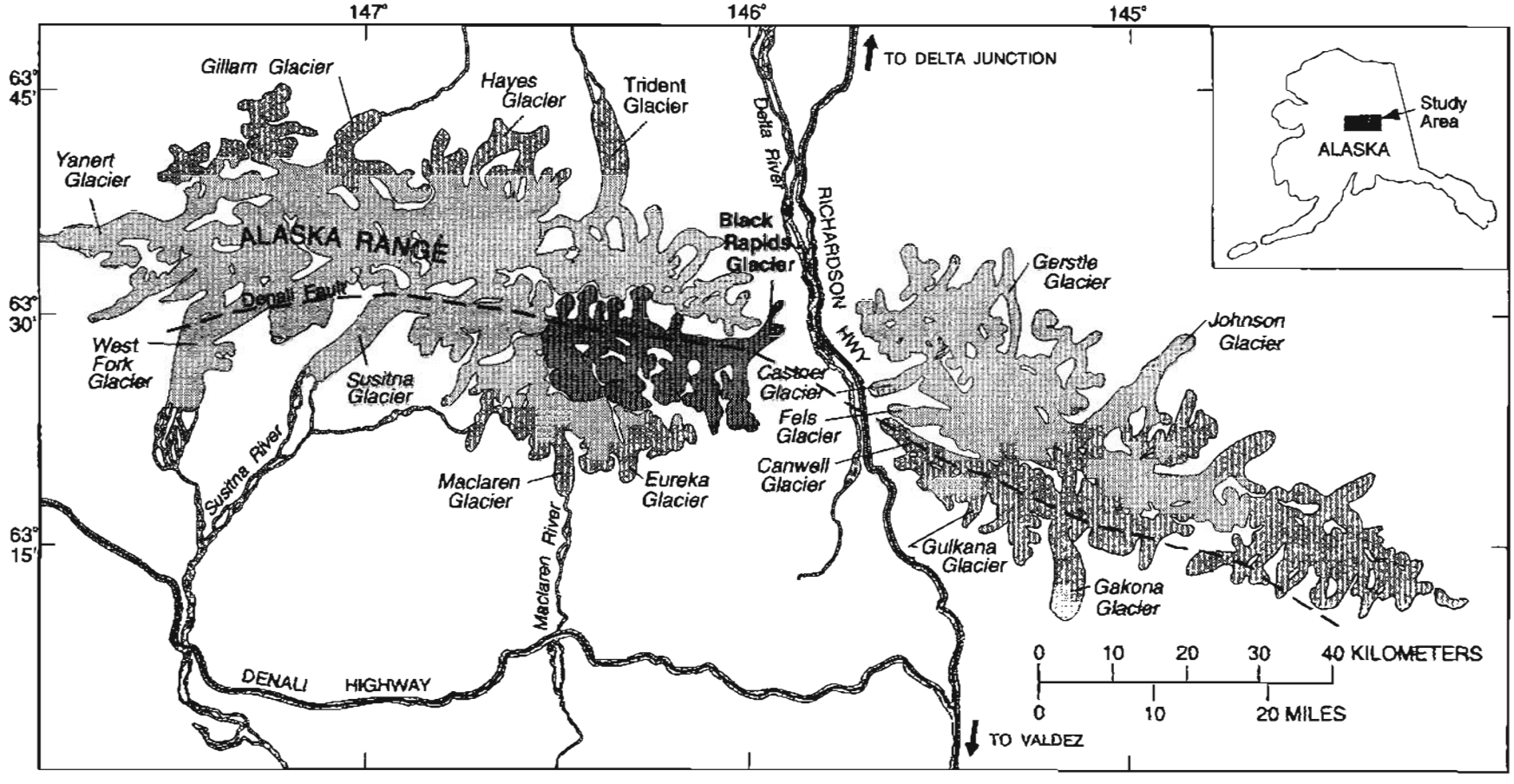


Figure 1. Location of study area, Black Rapids Glacier, Alaska.

Location and Description

Black Rapids Glacier (fig. 1) is located in the east-central Alaska Range just south of some of the highest mountains in the eastern half of the range. The ablation area of Black Rapids Glacier lies in an east-west valley formed along the Denali Fault trench; most of the accumulation area lies in two north-facing valleys. The eastern valley is a major tributary unofficially known as the "Loket tributary" (fig. 2). The western accumulation area is considered to be part of the main ice stream. Smaller tributaries contribute some ice to the main ice stream, as indicated by the moraine patterns shown in figure 2. The ice is temperate (Harrison and others, 1975). The total area of the glacier, including tributaries, is 246 km^2. An additional 31 km^2 of glacier ice are not connected to Black Rapids Glacier, giving a total glacier area of 277 km^2 in the basin. The drainage basin area is 473 km^2; the lower boundary of the drainage basin is defined by the stream-gaging site (fig. 2) established by the Universities of Alaska and Washington. Water draining from the Black Rapids Glacier basin enters the Delta River.

In May 1992, the glacier was about 43 km in length. Ice-cored moraine remnants of the 1936-37 surge lie 4 km in front of the 1992 terminus and within 2 km of the Delta River. (The Richardson Highway and the trans-Alaska oil pipeline lie less than 500 m east of the Delta River.) The present terminus, amid the jumble of stagnant ice-cored moraine left by the retreating glacier, now lies about 6 km from the Delta River. Black Rapids Glacier is remarkably uniform in width and surface slope: the mean width of the main branch is 1.8 km. The main branch of the glacier spans 1,800 m of altitude (850 to 2,650 m.)

Geologic evidence is visible in the Delta River valley from previous surges of Black Rapids Glacier. Reger and others (1993) established minimum ages for the surge moraines. They estimate that the minimum ages for the three visible moraines are 570 BP (or possibly as young as 210 BP), 1710 BP, and 3360 BP. Post and Mayo (1971) mapped the former shorelines of a lake formed in the Delta River valley when a surge of the Black Rapids Glacier crossed and dammed the Delta River.

Measurements

Measurement History

Black Rapids Glacier became the subject of scientific interest during the 1936-37 surge. The advancing glacier threatened to cross the Delta River, overrun the Richardson Highway, and crush the Rapids Roadhouse. Observations made during this exciting time were reported by Hance (1937), Moffit (1939), and Dr. Otto Geist (University of Alaska, written commun., undated). Moffit summarized bystander observations which indicated that Black Rapids Glacier advanced approximately 4 miles (6.4 km) between December 3, 1936, and March 7, 1937. Dr. Geist's unpublished observations of the advancing terminus are reported here (appendix A). Péwé and Taylor (1953) measured ablation at six sites on Black Rapids Glacier during the summer of 1952.

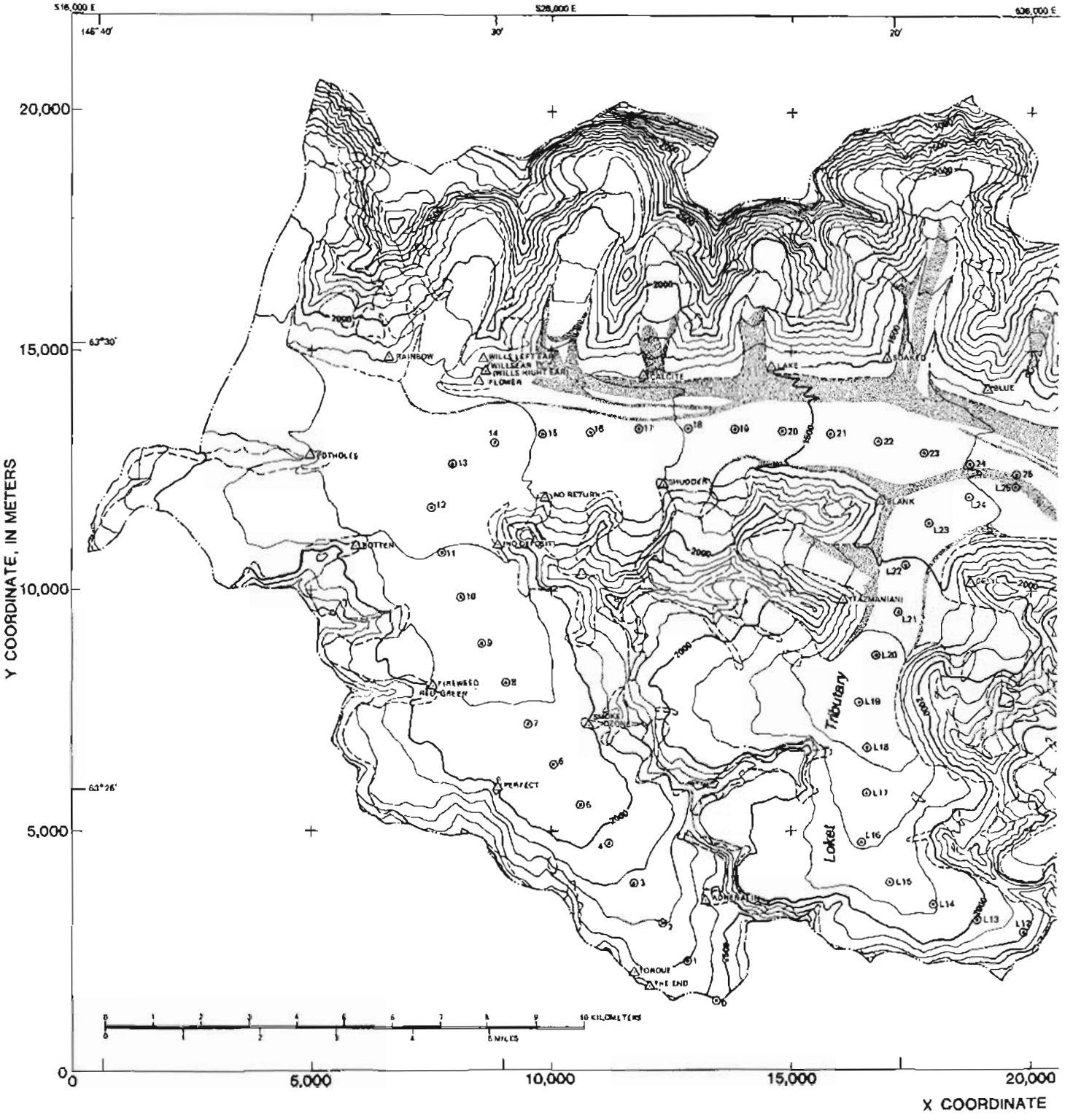
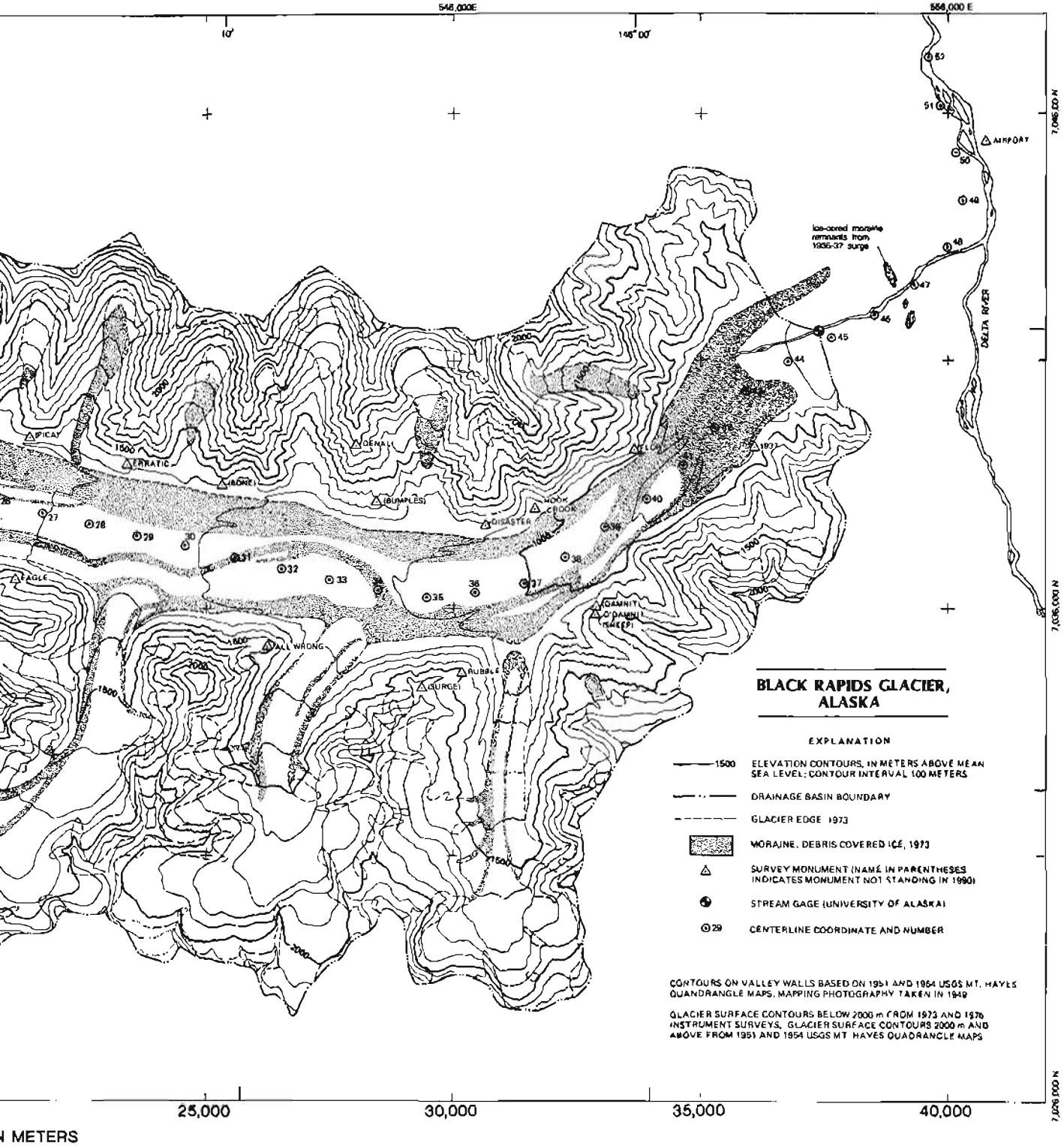


Figure 2. Black Rapids Glacier, Alaska, 1973.


548,000E
556,000 E
10'
146°00'
AIRPORT
DELTA RIVER
ice-cored moraine remnants from 1936-37 surge
PICAY
ERRATIC
BONE
DENALI
(BUMPLES)
DISASTER
HOOK CROOK
EAGLE
ALL WRONG
RUBBLE
(SURGE)
GAMNIT
O'DAMNIT
(MAKEEP)
1973
BLACK RAPIDS GLACIER, ALASKA
EXPLANATION
1500 ELEVATION CONTOURS, IN METERS ABOVE MEAN SEA LEVEL; CONTOUR INTERVAL 100 METERS
DRAINAGE BASIN BOUNDARY
GLACIER EDGE 1973
MORAINE, DEBRIS COVERED ICE, 1973
SURVEY MONUMENT (NAME IN PARENTHESES INDICATES MONUMENT NOT STANDING IN 1980)
STREAM GAGE (UNIVERSITY OF ALASKA)
29 CENTERLINE COORDINATE AND NUMBER
CONTOURS ON VALLEY WALLS BASED ON 1951 AND 1954 USGS MT. HAYES QUADRANGLE MAPS. MAPPING PHOTOGRAPHY TAKEN IN 1949
GLACIER SURFACE CONTOURS BELOW 2000 m FROM 1973 AND 1976 INSTRUMENT SURVEYS. GLACIER SURFACE CONTOURS 2000 m AND ABOVE FROM 1951 AND 1954 USGS MT. HAYES QUADRANGLE MAPS
25,000
30,000
35,000
40,000
N METERS

Interest in Black Rapids Glacier was renewed in 1968 by the proposal to build the trans-Alaska oil pipeline through the Alaska Range in the Delta River valley. Initial reconnaissance trips were made into the basin in 1970, 1971, and April 1972 by L.R. Mayo to assess the potential for another surge. In August 1972, a detailed monitoring program began when a large party of scientists from the U.S. Geological Survey, University of Alaska, and University of Washington installed geodetic control, surveyed, and set stakes along the main branch of the glacier and in the Loket tributary. The stakes were used to measure mass balance, ice velocity, and surface altitude. Stakes were maintained at 2-km intervals along the centerline of the main branch of the glacier until 1977.

The program was scaled down in 1977 to the 10 index sites that constitute the bulk of the data in this report. Eight of those sites are on the main branch of the glacier and two are on the Loket tributary. Mass balance, ice velocity, and surface altitude data were collected from these 10 index sites. The techniques used to gather these data are described in the next section.

The U.S. Geological Survey (USGS) monitoring program was suspended in 1987 and revived at a lower level in 1991 as a cooperative effort with the University of Alaska Fairbanks (UAF), and University of Washington (UW). Some measurements were made between 1987 and 1990 by UAF and UW; the data from this time period were analyzed and checked by the author to ensure the long-term continuity of the data set. Most of the field work in recent years has been done by field crews under the leadership of Professors William Harrison and Keith Echelmeyer from UAF. The number of sites monitored has been reduced to three in recent years.

Types of Measurements

At the core of the seasonal monitoring program at Black Rapids Glacier lie three basic measurements: surface mass balance, ice velocity, and surface altitude. These measurements are made at sites on the glacier with fixed horizontal coordinates. These fixed locations are referred to as the *index sites* and have been visited repeatedly for 18 years. During the visits, stakes were reset near the index sites in order to obtain a long-term data set in a fixed reference frame.

In addition to the mass balance, velocity, and altitude measurements made during every trip to the glacier, ice thickness was measured at selected points and on several cross-profiles of the glacier using ice-penetrating radar. The ice thickness measurements were usually made only once at a location. The change in thickness of the ice is the change in surface altitude, assuming that the altitude of the glacier bed is fixed.

Spatial Distribution

Measurements in this report are referred to a centerline coordinate system which originates at the head of the glacier (fig. 2.) See the section "Coordinate Systems" later in this report. For example, the 14 km index site is 14 km from the head of the glacier and approximately centered across the valley. In addition to the centerline coordinate system defined for the main glacier, measurements are also referred to centerline coordinates running up the Loket tributary. These coordinates are prefaced with an "L"— for example, L-22 km. Calculations of surveys are done in a local,

sea-level based, Cartesian coordinate system which is based on the UTM coordinate grid for the area; see the "Coordinate System" section for details.

The mass balance, ice velocity, and surface altitude were monitored at 10 sites on the glacier for 8 or more years: the 2, 4, 8, 14, 20, 26, 32, 38.3, L-19, and L-22 km sites (fig. 3). From July 1973 to July 1974, 16 sites were monitored at 2 km intervals along the centerline of main glacier branch (4, 6, 8 km, etc.). Profiles of ice velocity and thickness across the glacier were also made at several sites (fig. 4). In 1988, the monitoring was reduced to three sites: 8, 14, and 20 km.

Additional Studies

In addition to the data reported here, other researchers have made measurements of interest on Black Rapids Glacier. Sturm (1987) measured the movement of the "potholes" on Black Rapids Glacier using photogrammetry. William Harrison, Keith Echelmeyer, and Charles Raymond (UAF and UW, written commun., 1994) measured short-term ice movement using daily photographs, recorded seismicity, and measured vertical strain several times per hour over periods of many months. In the summer of 1993, a field party from UAF and UW spent several months making hourly and daily measurements of ice motion, surface altitude change, and bed seismic and radar reflectivity.

MASS BALANCE

Mass Balance Data Tables

Both mass balance observations and calculated mass balance results for each site on the glacier are reported in data tables in this report. Net balances were observed at each site [table 1 (p. 32 of this report), table 2 (p. 33-63), and data disk; see appendix B for information about the disk]. No attempt is made here to extrapolate the data to fixed dates or to extend the point balance measurements spatially over the glacier to obtain the mass balance for the glacier. The data could be extrapolated spatially using the area-altitude distribution reported in appendix C.

The reader should be aware of the time-transgressive nature of the yearly net mass balances measured between successive summer surfaces on large glaciers spanning wide ranges of altitude such as Black Rapids Glacier. The net balance is the change in ice storage at the glacier surface between two stratigraphic markers (the summer surfaces). Summer surfaces are formed at different times of the year at different altitudes on the glacier. The summer surface high in the glacier accumulation area can form (be fixed by autumn snowfall) one or two months before the summer surface forms low in the ablation area.

The example calculations shown below demonstrate how mass balance observations made during a typical site visit (fig. 5) are used to calculate mass balance results.

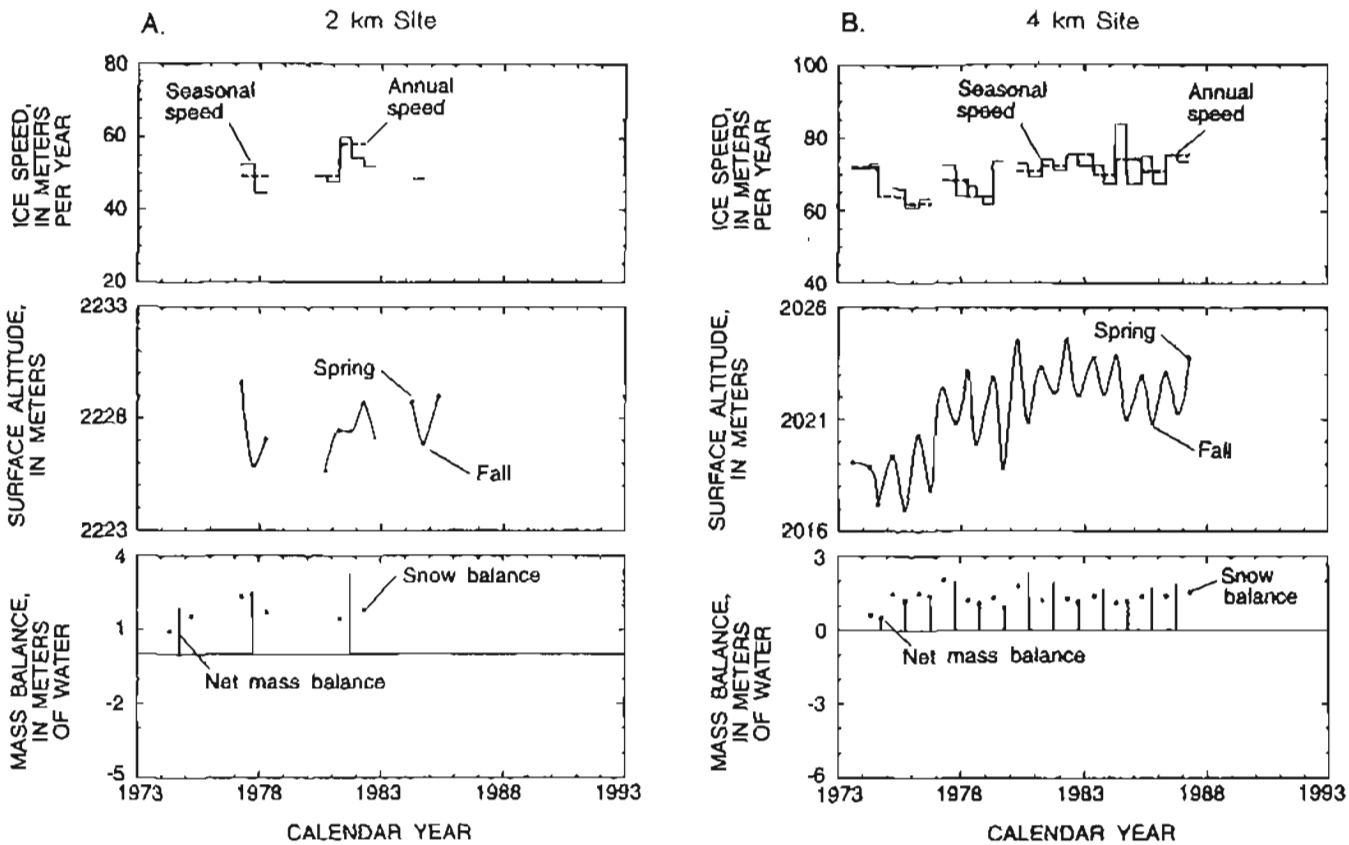


Figure 3. Ice speed, surface altitude, and mass balance at Black Rapids Glacier.
[Ablation area surface altitudes are plotted as "ice equivalent," which is the ice surface altitude plus the thickness of the snow converted to its equivalent thickness of ice. At the 2, 4, 8, and L-19 km sites, the measured surface altitudes are plotted. Snow balances are plotted on the date of observation. The net balance for a year is plotted at three-fourths of the way through the year: for example, the 1978 net mass balance is plotted at 1978.75.]

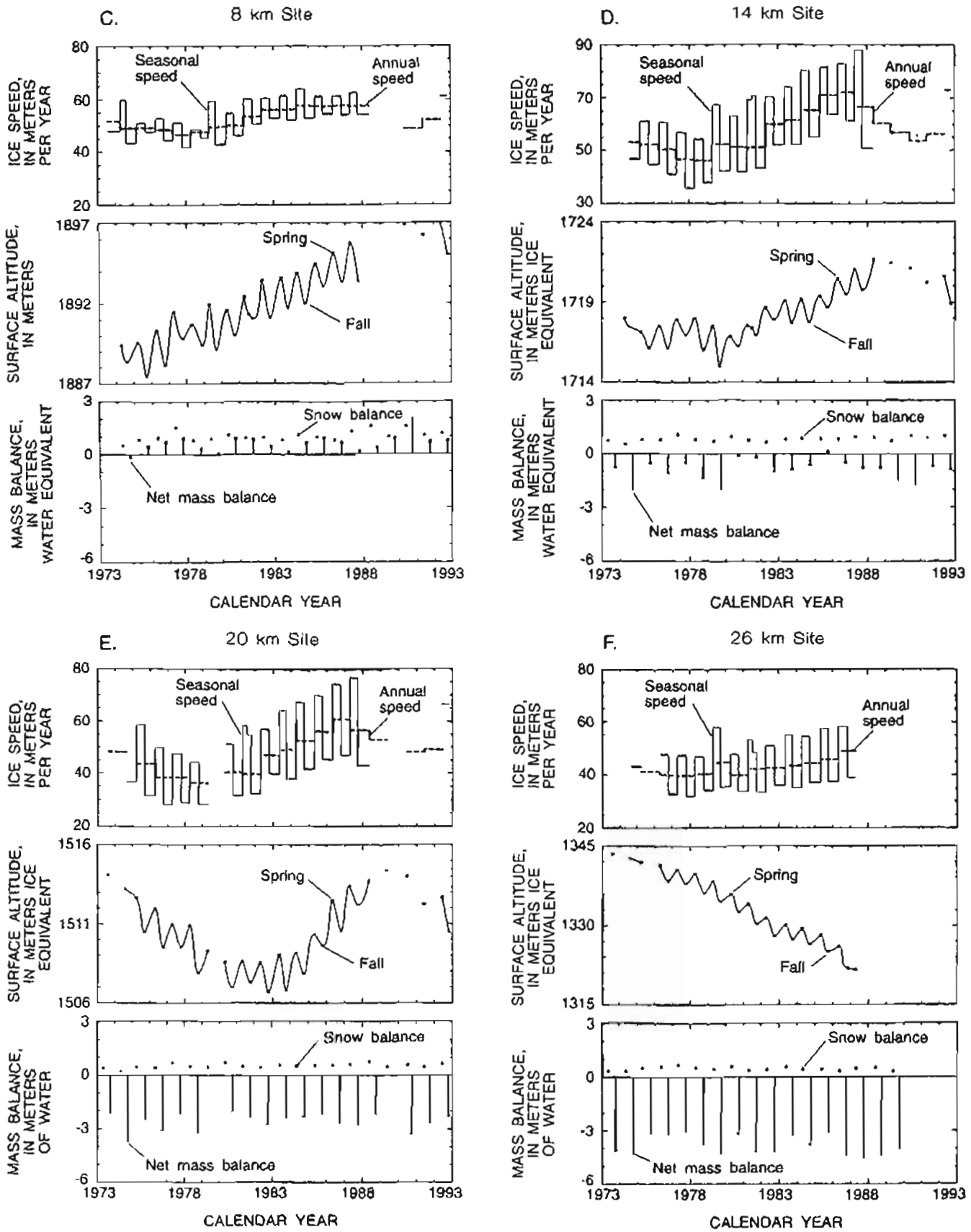


Figure 3. Continued.

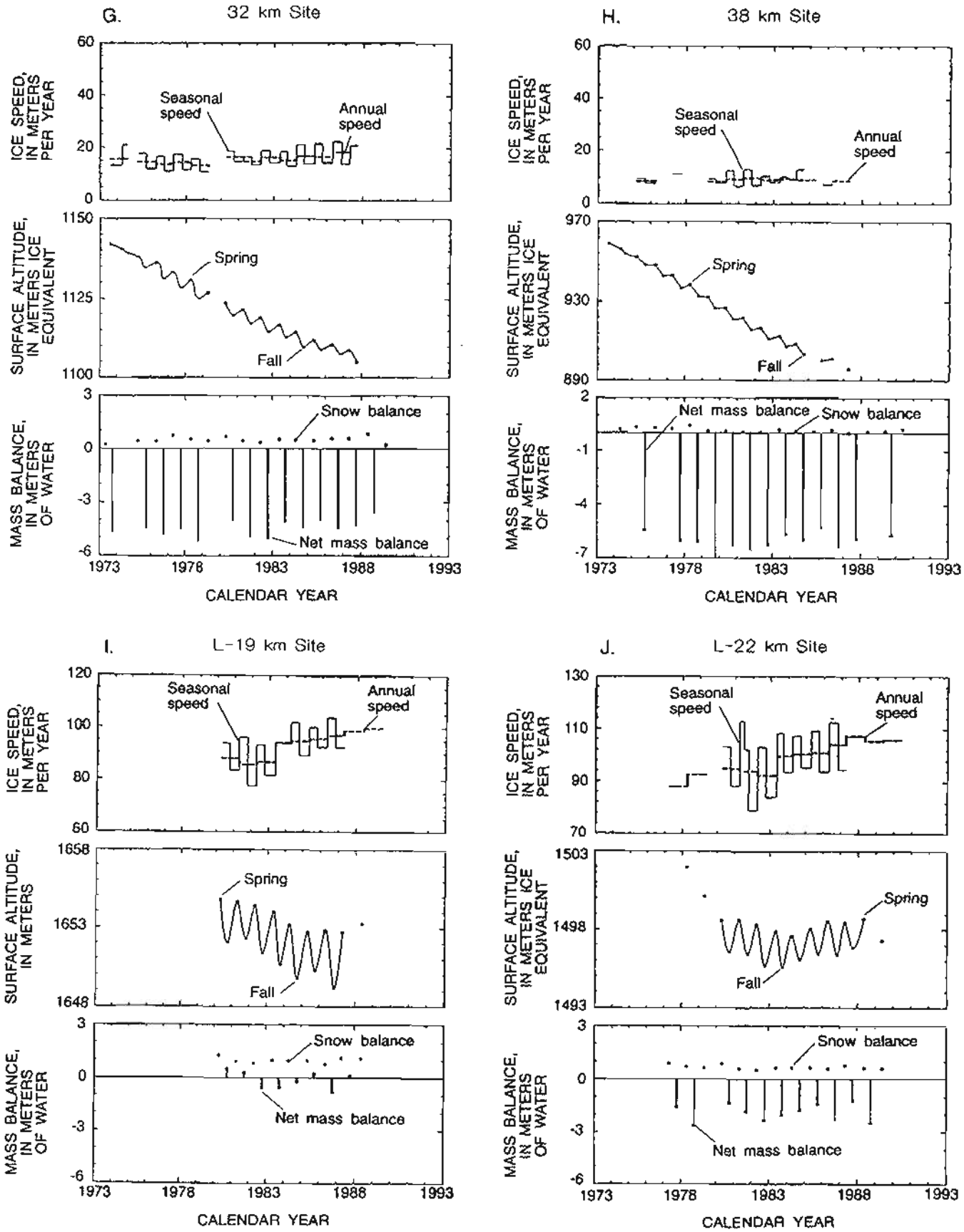


Figure 3. Continued.

EXPLANATION

Drainage basin boundary
Moraines
Glacier area
Non-glacier area

Profile site	Observation date	
	Ice thickness	Ice velocity
14 km	May-90	*no data*
15 km	May-90	May-90 to July-90
20 km	May-90	April-87 to April-88
24 km	*no data*	March-75 to March-76
25.9 km	March-76	*no data*
32 km	*no data*	July-73 to July-74
34.4 km	April-87	*no data*

Figure 4. Cross-profiles of ice velocity and thickness, Black Rapids Glacier.

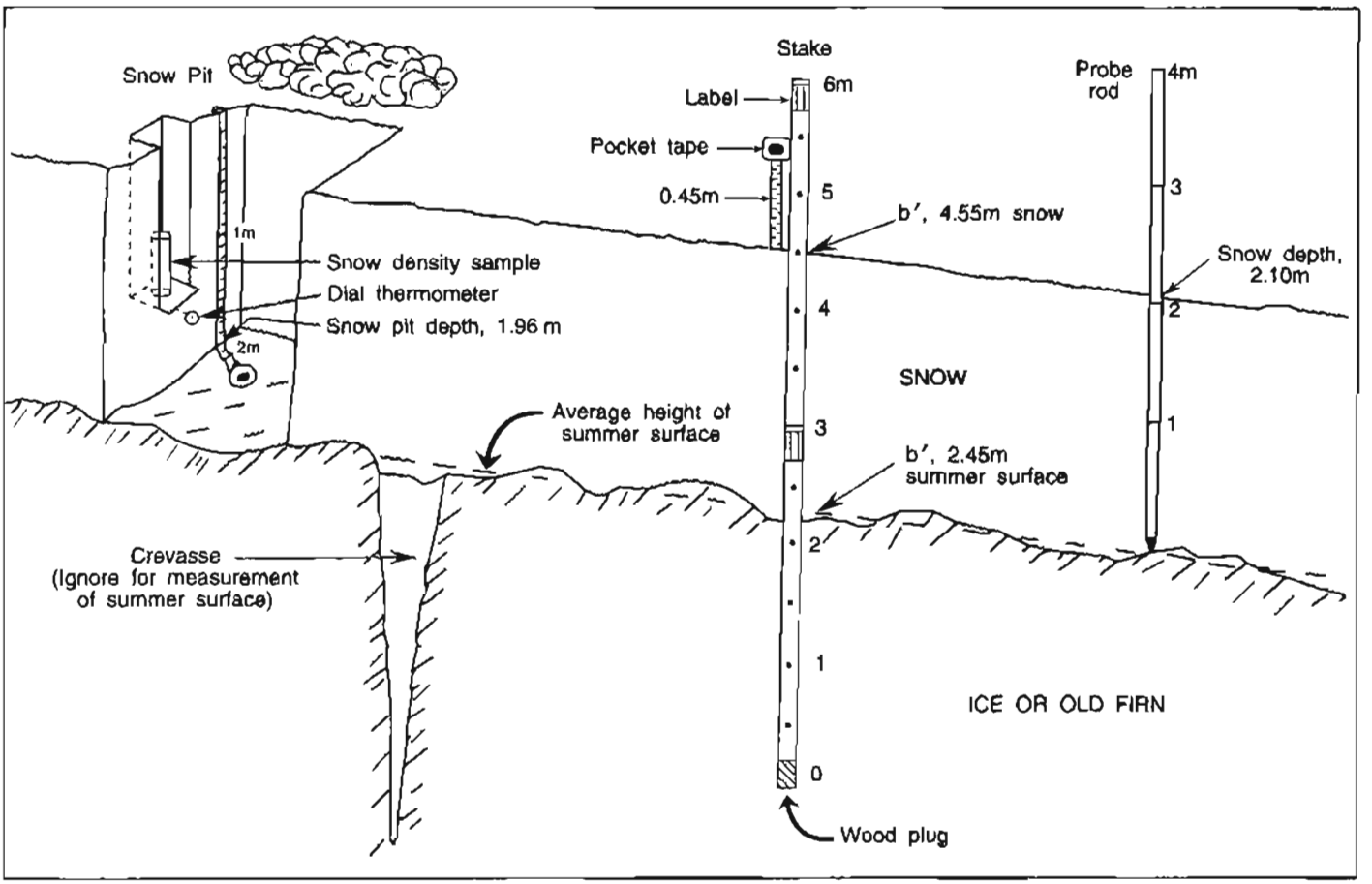


Figure 5. Glacier mass balance observation site showing snow pit, stake, and snow probe measurements.

Example Calculations

Following are three examples to illustrate the calculations used to obtain mass balances from field observations. Snow and firn densities at a site are frequently estimated using our intuition, drawing on the history of observed densities at the site, at nearby sites, and at nearby Gulkana Glacier. The stakes are labeled with the year of installation as the first number and the site location as the second number—for example, stake 82-14. The first two examples are from the ablation area.

Ablation Area

The first example illustrates a year in which multiple observations were made to a summer surface during the measurement year (table 3, p. 64). The multiple summer surface observations give different results, because the ice surface is uneven, and are reconciled to a single value.

The site was visited on March 24, 1976, when the snow surface at stake 75-14 was at 8.46 m stake height, b'. Five snow depth probings had an average of 2.23 m. The five probe depths were $n = 5$ samples, for a mean snow thickness of 2.23 m and standard error of 0.01 m. Therefore, the summer surface ($b'ss$) was at 6.23 m on stake 75-14 (8.46 - 2.23 = 6.23).

The next visit to the site was on September 13, 1976. At stake 75-14, b' was 5.31 m. At the same time, the snow was probed once and the depth was 0.27 m. Thus, the observed summer surface was at 5.04 m on stake 75-14. It is necessary to look ahead to the next observation of this stake to get the estimated summer surface. On March 19, 1977, the summer surface ($b'ss$) on stake 75-14 was observed to be 4.91 m. There are two measurements of the 1976 summer surface [September 1976 (5.04 m) and March 1977 (4.91 m)], and their values must be reconciled. The estimated summer surface is the average of these two numbers: 4.97 m.

The amount of ice ablation is calculated next. The ice thinned 1.26 m between April and September (6.23 - 4.97 = 1.26). The ice balance, $b(i)$, for the 1976 balance year is -1.26*0.90 = -1.13 m_{we} (meter of water equivalent). A similar calculation for stake 76-14 gives $b(i)$ to be -1.04 m_{we}.

The bottom line of table 3 presents the results for the 1976 balance year. Two stakes were under observation at the site during 1976, and each gave a slightly different result. The different results are reconciled by averaging the results from the two stakes, giving an ice balance of -1.09 m_{we} and a net balance of -1.09 m of water for the 1976 balance year.

The second example is another common situation that also occurs in the ablation area (table 4, p. 64). In this case, an ice surface is present on the fall trip to the glacier, so the summer surface has not yet formed and must be observed on the following spring trip.

Stake 75-20 was installed and the first readings for the 1975 balance year were made on March 2, 1975. The summer surface was at 8.46 m on the stake. On August 25, 1975, the fall trip was made to the glacier. At this time, the stake reading was 6.05 m at an ice surface. The ice balance between March and August 1975 was -2.16 m_{we} (= -2.41*0.90), and the net balance up to that date is -2.16 m_{we}, recorded in the b_n column. Additional ablation occurred during the remaining part of the summer, and on the next trip to the glacier on March 24, 1976, the 1975 summer surface ($b'ss$) was observed at 5.79 m. Thus, the net mass balance (b_n) for the 1975 balance year was the ice melt $b(i)$ = -2.40 m_{we}.

Accumulation Area

Analysis of field data from the accumulation area is more challenging than analysis of ablation area data because of complications of working with firn rather than glacier ice. A summer surface on firn will stop a snow probe rod less reliably than an ablation area ice surface will; the firn itself changes, by compacting, moving relative to the stake, and freezing water in its pore spaces. The third example calculation (table 5, p. 65), which illustrates how the data are analyzed, is from the 8 km site in the accumulation area of the glacier.

The first data for the 1980 balance year were gathered on March 27, 1980, yielding a stake height reading (b') of 8.33 m at a snow surface and an average depth of 3.11 m from five probings. The 1979 summer surface was observed to be at 5.22 m (8.33 - 3.11) stake height. The snow density was estimated to be 0.36 g/cm^3 . Thus, the snow balance[$b(s)$] and the net balance (b_n) on that date are 1.12 m_{we}, $b_n = b(s) = \rho(s)*d(s)$. Internal accumulation for the year had not yet begun; the snow was still cold and dry.

At the following visit on September 4, 1980, the new snow surface was at 6.83 m stake height. A pit was dug 0.32 m through the thin new snow to the summer surface (new firn with a dirty surface), giving an observed summer surface height of 6.51 m. Assuming that the 1979 summer surface (5.22 m) observed in March 1980 had not changed, then the 1980 increment of new firn was 6.51 - 5.22 = 1.29 m. The firn density was estimated to be 0.51 g/cm^3 , giving a new firn balance, *b(f)*, of 0.66 m_{we}. The internal accumulation, *b(k)*, was estimated to be 0.27 m of water, using an estimated summer surface temperature in March 1980 of -7.2°C . The net balance for the year, b_n, is the sum of the firn, *b(f)*, and internal, *b(k)*, accumulations: 0.66 + 0.27 = 0.93 m_{we}.

Error Analysis: Uncertainties in the Mass Balance Site Observations

The uncertainties of the mass balance results are a combination of the uncertainties in stake readings, snow or firn density, snow depth, summer surface temperature, and internal accumulation calculations. The standard error of the snow depth can be calculated if multiple snow probings are made and is a measure of the uncertainty in the snow depth measurement. The rest of these uncertainties must be estimated because they were not observed with a sufficient number of independent samples to calculate a standard error of observation. As examples, a site generally has only one or two stakes, and when snow density is measured, usually only one pit is dug and sampled. Error estimates are reported in table 6 (p. 65).

The error estimates for individual quantities are combined using standard techniques: uncertainties in sums are combined in quadrature (the square root of the sum of the squares); for uncertainties in products, the fractional errors are combined in quadrature (Taylor, 1982.) Examples of uncertainties in common situations are illustrated in table 7 (p. 66). Most of the uncertainty in the accumulation area arises from the uncertainty of the firn depth and density.

Not addressed in these uncertainty estimates are errors caused by simple blunders that cannot be checked independently. The most troublesome blunder is faulty snow depth probing in the accumulation area. It is possible to probe through a summer surface if it is not well consolidated, or for the probe rod to stop on an ice layer above the summer surface. The faulty probing could usually be eliminated by studying the series of observations at a site and identifying inconsistencies. However, it is possible that a few of the data reported here are, in fact, substantially in error.

Snow Pits

Twenty-three snow pits were studied on Black Rapids Glacier (appendix D). Snow density and temperature were measured in each pit. Appendix D contains the detailed data tables and uncertainty calculations.

Temperatures at the Summer Surface

The summer surface temperature used to estimate internal accumulation (Trabant and Mayo, 1985) at a site was measured occasionally. However, in most cases it had to be estimated from observations at other sites on Black Rapids Glacier or from unpublished observations at Gulkana Glacier. Observed and estimated summer surface temperatures are listed in appendix E.

Snow Data for 1970-72

During the reconnaissance phase of the Black Rapids Glacier monitoring program (1970-72), some snow depth data were gathered prior to the main program. Snow depth data were gathered on August 27, 1970 and April 23, 1972 (table 8, p. 66). The most extensive snow probing ever done on Black Rapids Glacier (April 2-4, 1972) is plotted on figure 6 (p. 16-17).

ICE VELOCITY

Velocity Along the Glacier Centerline

Ice velocities at the 10 index sites on Black Rapids Glacier are reported in table 9 (p. 67-76) and plotted in figure 3. Additional velocities measured along the centerline are reported in table 10. Typically, two measurement trips were made to the glacier each year. However, in some years additional trips were made as a supplement to the usual spring and fall trips. These data are also reported in table 10 (p. 77-78). A longitudinal profile of ice velocity with a marker every 2 km along the glacier centerline from 4 to 36 km (except for 24 km) was measured from July 1973 to July 1974 (table 11, p. 79). This longitudinal profile is plotted in figure 7.

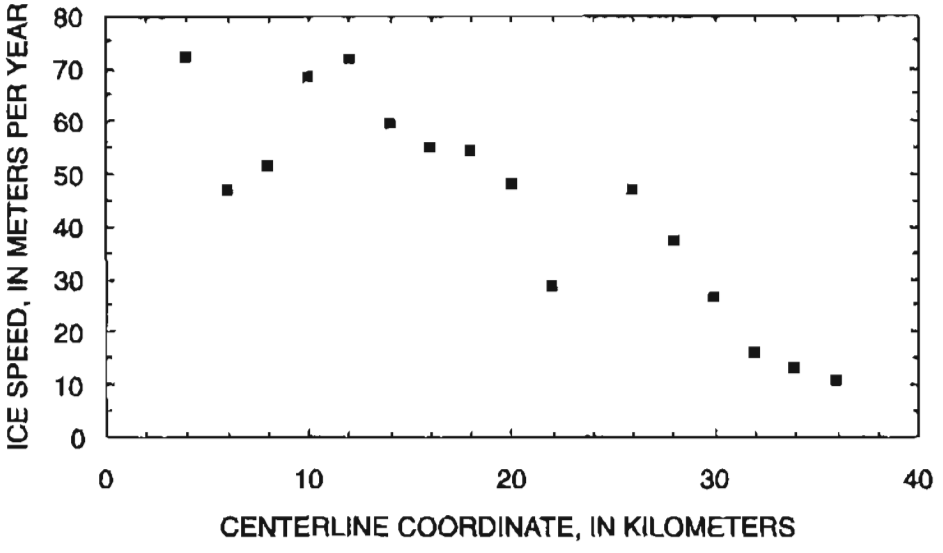


Figure 7. Longitudinal profile of ice speed at the surface of Black Rapids Glacier measured from July 1973 to July 1974. [See table 11 for data.]

The ice velocity at a site was determined by surveying the same stakes used for gathering mass balance data. Commonly, a theodolite was set near the stake, and a three-point resection survey was done to locate the theodolite. Foresight surveys were then made to the stake to locate it. On other occasions, particularly in the early years, the theodolite was set up over a monument and

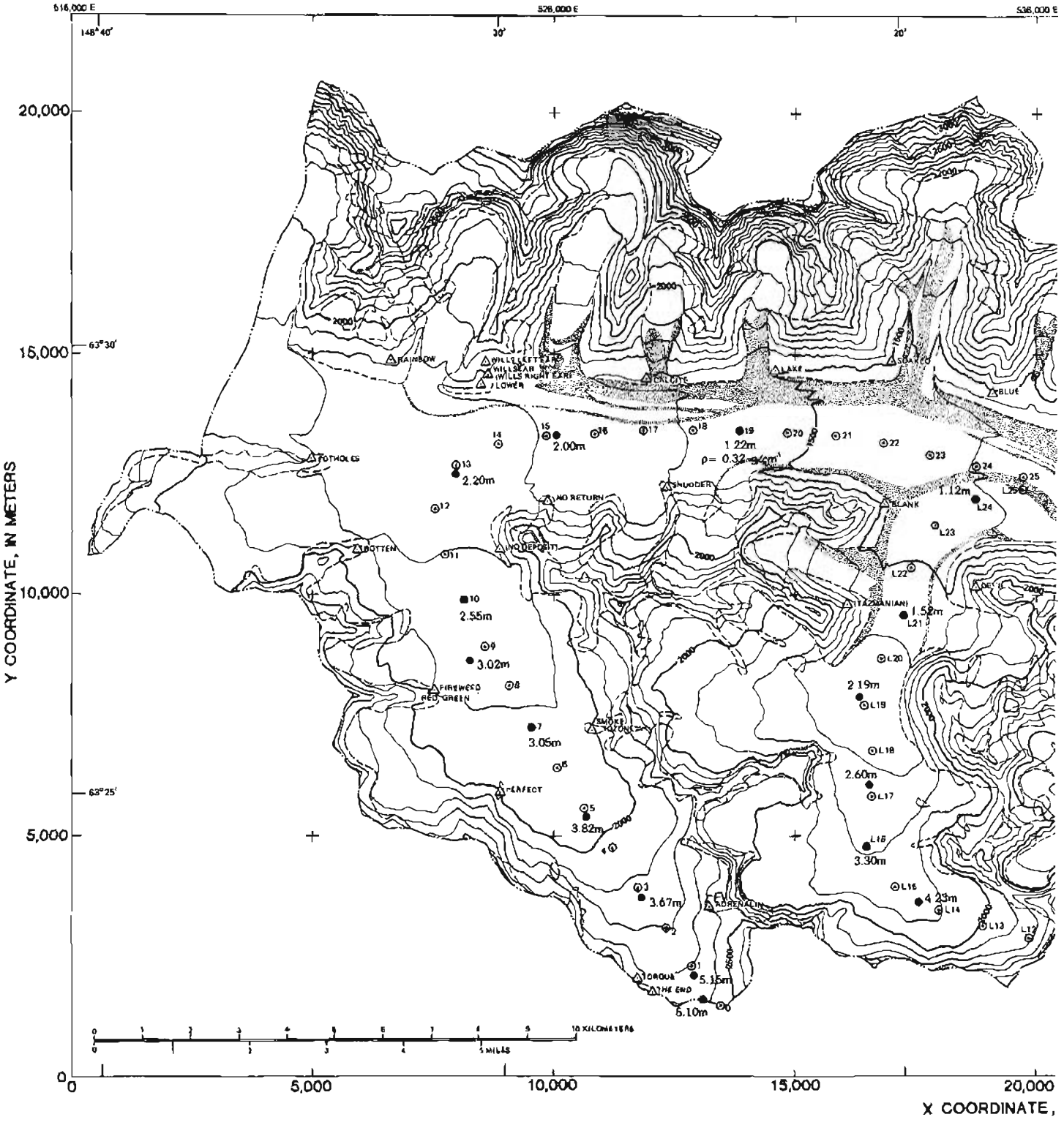
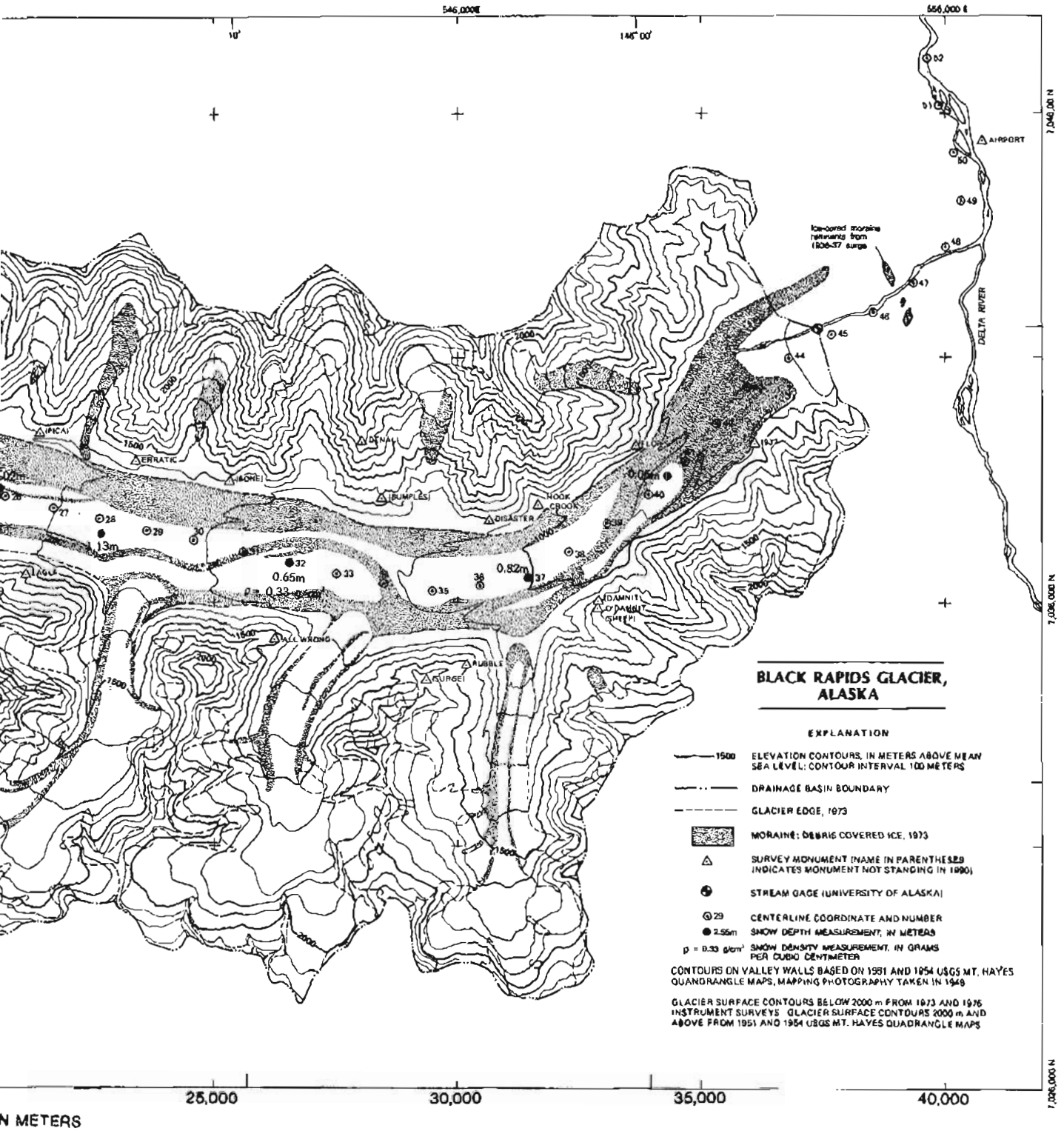


Figure 6. Snow depth observations of April 2-4, 1972, Black Rapids Glacier. [Snow depths were measured by probing. See *Mass Balance Data Tables* section in text for description of snow probing techniques. See Appendix D for snow pit techniques.]


BLACK RAPIDS GLACIER, ALASKA
EXPLANATION
1500 ELEVATION CONTOURS, IN METERS ABOVE MEAN SEA LEVEL; CONTOUR INTERVAL 100 METERS
DRAINAGE BASIN BOUNDARY
GLACIER EDGE, 1973
MORAINE; DEBRIS COVERED ICE, 1973
SURVEY MONUMENT (NAME IN PARENTHESES INDICATES MONUMENT NOT STANDING IN 1990)
STREAM GAGE (UNIVERSITY OF ALASKA)
29 CENTERLINE COORDINATE AND NUMBER
2.55m SNOW DEPTH MEASUREMENT, IN METERS
ρ = 0.33 g/cm³ SNOW DENSITY MEASUREMENT, IN GRAMS PER CUBIC CENTIMETER
CONTOURS ON VALLEY WALLS BASED ON 1951 AND 1954 USGS MT. HAYES QUADRANGLE MAPS, MAPPING PHOTOGRAPHY TAKEN IN 1949
GLACIER SURFACE CONTOURS BELOW 2000 m FROM 1973 AND 1976 INSTRUMENT SURVEYS GLACIER SURFACE CONTOURS 2000 m AND ABOVE FROM 1951 AND 1954 USGS MT. HAYES QUADRANGLE MAPS
546,000E
656,000 E
146° 00'
7,046,000 N
7,026,000 N
7,006,000 N
25,000
30,000
35,000
40,000
N METERS
AIRPORT
DELTA RIVER
Ice-cored moraine remnants from 1936-37 surge
ERRATIC
BUMPLES
DISASTER
HOOK CROOK
ALL WRONG
RUBBLE
SURGE
0.13m
0.65m
0.82m
0.05m

foresight surveys were made to the stake using long-range distance measuring instruments. Both the resection and foresight methods used for this work are explained by Mayo and others (1979) and by Mayo and Trabant (1982). These surveying methods include treating the atmospheric refraction of light as a measured variable, which is necessary for getting reliable vertical results for surveys over the distances at Black Rapids Glacier.

The program monitors changes in Black Rapids Glacier at specific sites with locations that are fixed in horizontal space—the index sites. In order to measure the velocity continuously at a fixed location near the index sites, stakes must be replaced regularly. The typical procedure is to place a stake on the spring trip at a distance of about one year's flow displacement upstream from the index site. The following spring, the stake will have moved to a location near the index site. During the second spring trip after placement, the stake will be about one year's flow displacement downstream from the index site. At this time, a new stake is placed about one year's flow displacement above the index site. Both the old and new stakes are surveyed, and the 2-year cycle is repeated. At sites low in the ablation area where the ablation is large, stakes must be replaced yearly to prevent them from melting out.

In the velocity data tables (table 9), the *date* of the survey and the unique *stake name* are reported in the two left columns. The next columns contain the *coordinates* of the base of the stake (in the local system, see "Coordinate Systems" section). Because stakes do not remain perfectly vertical after they are set—they lean or bend due to wind loading, snow loading, ice motion, and ice melt—a surveying technique to more accurately locate the base of the stakes was used (Hodge, 1972). It is assumed that the base of the stake is the most representative point in the observation system and therefore it was used for the velocity calculations. To calculate lean, two points are surveyed on the stake and the coordinates of the base of the stake are calculated. This method was applied to all the stake data from 1978 to 1987. Prior to the adoption of this technique in 1978, the stakes' base coordinates are calculated from a single survey of the stake as if the stake were vertical. The pre-1978 flow data are, therefore, slightly less accurate than the later data. Since 1987, about half of the stakes were surveyed with enough detail to make lean corrections, so some of the data from recent years are less accurate than the data from 1978 to 1987.

The time *period* in days between measurements and the length of the three-dimensional *displacement* vector are reported in the next two columns of table 9. From the period and displacement, a velocity vector was calculated; its magnitude is called the *seasonal speed*. This speed is the simple displacement speed measured between two successive surveys, which assumes the flow was in a straight line. Seasonal changes in ice speed are easily seen in the sawtooth patterns of the seasonal speeds plotted in figure 3. The *flow azimuth* is the horizontal direction of the flow, measured positive clockwise from north in the local grid. In the next two columns of table 9, the vertical components of flow are reported. The *vertical displacement* is the change in altitude of the base of the stake between successive surveys. The *vertical speed* is calculated over the measurement period. Finally, in the right-hand column, the *annual speed* is reported. The annual speed is calculated between two spring measurements whenever possible. It is reported separately because it provides a better estimate of the average speed over the year. Also, in most recent years, only one trip per year was made to the glacier, and it was desirable to compare speeds for the entire period of record.

It is important to note that the average velocities reported are the velocities calculated between measurements. The observation dates are similar but not identical from year to year. Black Rapids Glacier undergoes an annual cycle of speeding up and slowing down, so the point in this cycle at which the survey is made affects the calculated velocity. It is particularly important to keep this in mind when interpreting changes in seasonal velocities.

Uncertainty in the results using these surveying techniques was addressed by Mayo and others (1979). For Black Rapids Glacier, a set of four surveys was examined for uncertainties. Uncertainty in the horizontal coordinate was estimated to be ±0.05 m. The uncertainty of the vertical coordinates is approximately ±0.05 m. The uncertainty in the position of the base of the stake, determined by using the lean calculations described above, was estimated to be 0.25 m. Given these uncertainties, the estimated uncertainty in the displacement calculated between two surveys is:

$$\pm 0.37 \text{ m} = \pm\sqrt{0.05^2 + 0.05^2 + 0.05^2 + 0.05^2 + 0.25^2 + 0.25^2}\text{m}.$$

Cross-Velocity Profiles

Four profiles of velocity across the direction of ice flow have been measured at Black Rapids Glacier [table 12 (p. 80-81) and figure 8]. The profile at 15 km in 1990 was measured using markers riding on the surface of the glacier. They were set out on top of the snow in May and resurveyed in July after the snow had melted. Only the horizontal velocities are reported for this 15 km profile.

Range-Line Speed Measurements

In the early days of the Black Rapids Glacier project (1971-74), ice speeds were measured by visually lining up pairs of markers fixed on rock or moraine adjacent to the glacier, similar to sighting a rifle. First, a stake was drilled into the ice in line with the markers. On the next visit to the site, the observer would position himself in line with the markers, effectively occupying the same position of the stake as when it was installed. The distance between the observer and the stake would then be measured with a tape, giving the stake displacement between observations. These range-line speed data can be found in table 13 (p. 82).

SURFACE ALTITUDE

Monitoring of Index Site Altitudes

Glacier surges are a cyclic process involving mass accumulation on the upper glacier and mass wastage on the lower glacier in the years between surges (Bindschadler, 1982). To monitor these geometric changes in Black Rapids Glacier, the surface altitudes of index sites fixed in horizontal space were measured repeatedly. A practical technique for measuring these index site altitudes (Mayo and Trabant, 1982) involves finding the approximate location of the site by going to the stake near the index site, and then surveying three points on the glacier surface around the index site to define a plane. The altitude of that plane at the index site horizontal coordinates (see table 21 later in report) is the observed index site altitude.

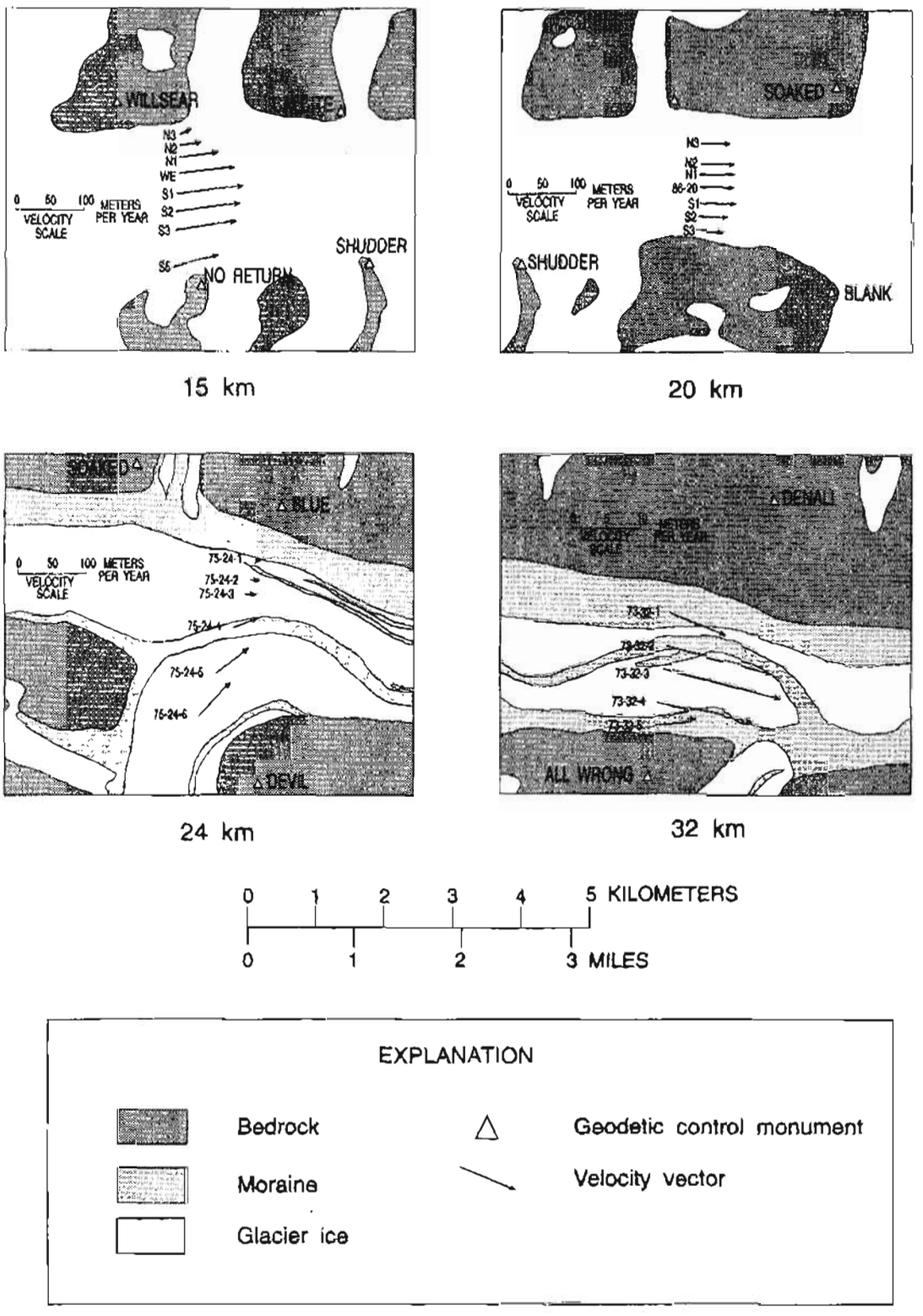


Figure 8. Ice velocity cross-profiles, Black Rapids Glacier [See figure 4 for locations. Note velocity scale change in 32 km profile. Data are in table 12.]

Surface altitude measurements at the 10 primary index sites are reported in table 14 (p. 83-92) and plotted in figure 3. In the tables, the *surface altitude* is the observed surface altitude. The *ice equivalent altitude*, a useful quantity for making ice dynamics calculations, is calculated by converting the measured snow depth into its equivalent ice depth and adding it to the measured ice surface altitude.

The surveying technique using three points to measure index site altitude was not implemented fully in the monitoring program at Black Rapids Glacier until 1978. Index altitudes reported prior to 1978 were calculated using the surface plane orientation measured by surveying three points in 1978 and adjusting the altitude of the plane up or down using a single glacier surface point surveyed near the index site.

The uncertainty in the vertical surveys is approximately ±0.05 m. Further uncertainty in the index site altitudes is derived from the possibility that the three points chosen to define the surface are not representative of the average glacier surface. If an average value of ±0.25 m is assigned to this uncertainty, the combined error, including both terms, is ±0.25 m.

Profiles for 1973 and 1976, and Map of 1972

Detailed surveys of the glacier surface were made in July 1973 and March 1976. These altitude point measurements are reported in table 15 (p. 93-94). Their locations and values are shown on figure 9.

A map of the glacier surface in 1973 (fig. 2) was drawn because the photogrammetric topographic maps currently published by the USGS were made from vertical air photographs taken in 1948-49 and 1954 (Mt. Hayes B-4 quadrangle) and 1950 and 1956 (Mt. Hayes B-5 quadrangle). The glacier surface has changed substantially in the time since the map photographs were taken. The 1973 map in this report was not made using photogrammetric methods. The glacier surface contours were drawn using the point data from the 1973 and 1976 geodetic surveys. Most of the point survey data were near the glacier centerline, so the contours were extended across the width of the glacier using contour shapes from the existing USGS quadrangle maps. The glacier boundary and moraine positions were drawn using oblique air photographs taken in 1973. The contours of static features, such as valley walls, were converted manually from feet to meters from the 1954 USGS maps. The 1973 map in this report is qualitatively correct, but there could be substantial quantitative errors, particularly in regions of the glacier where no surveying was done.

Altimeter Measurements for 1970

During the initial phase of the Black Rapids Glacier monitoring program, some reconnaissance surface altitude data were gathered. The altitudes shown in table 16 (p. 94) were measured using a surveying altimeter of unknown accuracy. Locations were noted in the field by map reading and are accurate to about 200 m.

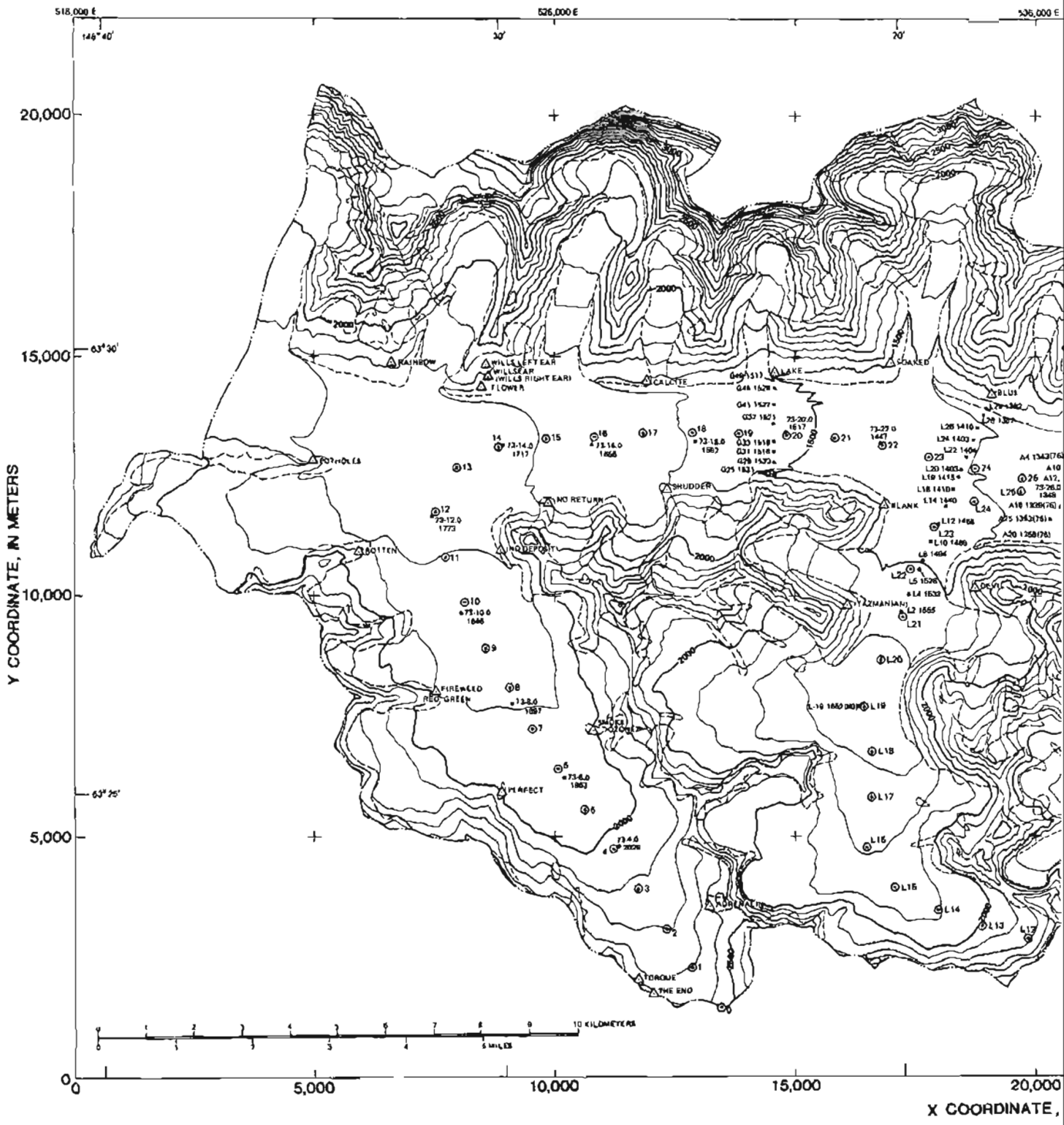
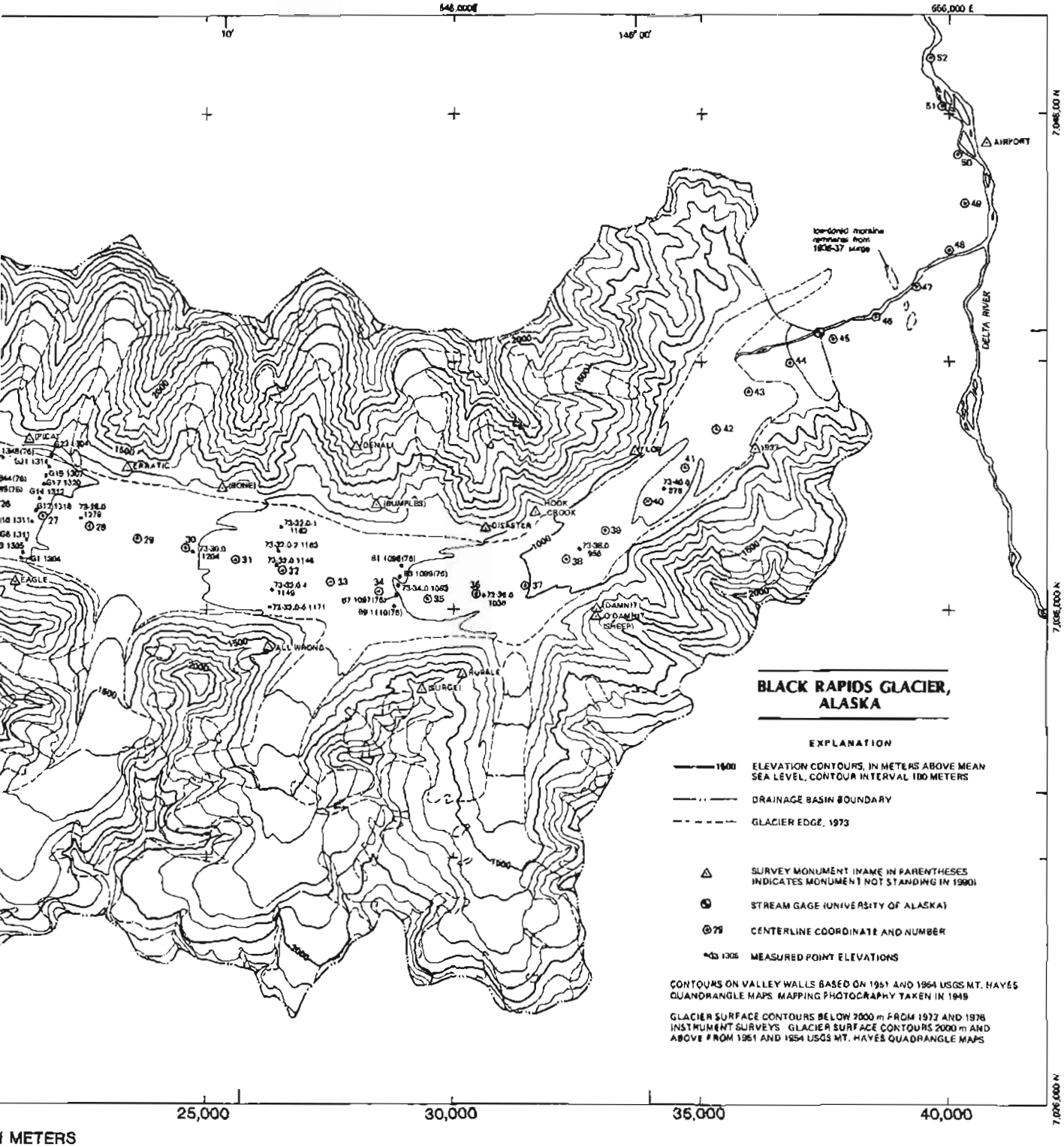


Figure 9. Point altitude measurements, 1973 and 1976, Black Rapids Glacier. [See table 15 for data.]


BLACK RAPIDS GLACIER, ALASKA
EXPLANATION
ELEVATION CONTOURS, IN METERS ABOVE MEAN SEA LEVEL, CONTOUR INTERVAL 100 METERS
DRAINAGE BASIN BOUNDARY
GLACIER EDGE, 1973
SURVEY MONUMENT (NAME IN PARENTHESES INDICATES MONUMENT NOT STANDING IN 1980)
STREAM GAGE (UNIVERSITY OF ALASKA)
CENTERLINE COORDINATE AND NUMBER
MEASURED POINT ELEVATIONS
CONTOURS ON VALLEY WALLS BASED ON 1951 AND 1954 USGS MT. HAYES QUADRANGLE MAPS. MAPPING PHOTOGRAPHY TAKEN IN 1949
GLACIER SURFACE CONTOURS BELOW 2000 m FROM 1972 AND 1976 INSTRUMENT SURVEYS. GLACIER SURFACE CONTOURS 2000 m AND ABOVE FROM 1951 AND 1954 USGS MT. HAYES QUADRANGLE MAPS
AIRPORT
DELTA RIVER
ICE-CORED MORAINE REMNANTS FROM 1936-37 SURGE
ERRATIC
(BONE)
(BUMPLES)
DISASTER
HOOK CROOK
EAGLE
ALL WRONG
SURGE
25,000
30,000
35,000
40,000
METERS

ICE THICKNESS

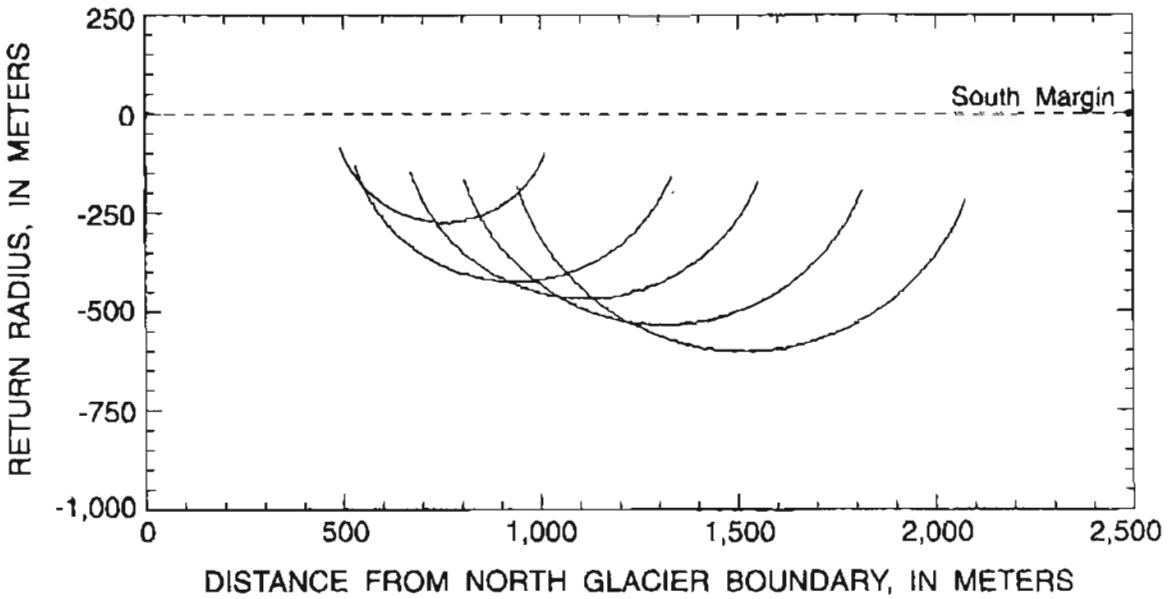
Ice thicknesses on Black Rapids Glacier were measured using ice-penetrating radar apparatus (Watts and Wright, 1981). The results of the ice radar surveys are reported in table 17 (p. 96) and plotted in figure 10. The *delay time*, t_d, read from the screen of an analog oscilloscope, is reported. The 1990 data were recorded using a digital oscilloscope. The delay time is the length of time elapsed between the triggering of the oscilloscope by the direct air wave and the return of the reflected wave from the glacier bed. The return time and *antenna separation* define the ellipsoid from which the returning signal was reflected. The length of the semi-major axis of this ellipsoid is $A = \frac{c_{ice}(t_d + s/c_{air})}{2}$ where c_{ice} is the speed of light in ice (168 x 10^6 m/s), s is the antenna separation, and c_{air} is the speed of light in air (300 x 10^6 m/s). The length of the semi-minor axis of the ellipsoid, $R = \frac{\sqrt{A^2 - (s/2)^2}}{2}$, which is called the *return radius*, is a first approximation to the ice depth (Mayo and Trabant, 1982). To get true ice depths, more interpretation must be made: the data must be migrated, a calculation not made in this data report.

The ice radar measurements are located with different degrees of accuracy. Some measurement locations were surveyed to sub-meter accuracy using standard surveying techniques. Some of the other data are positioned using map readings (about ±200 m); some were surveyed short distances with a Brunton compass and tape measure from stakes located accurately by standard surveys (±10 to 20 m.) The method of positioning is listed in the right-hand column of table 17.

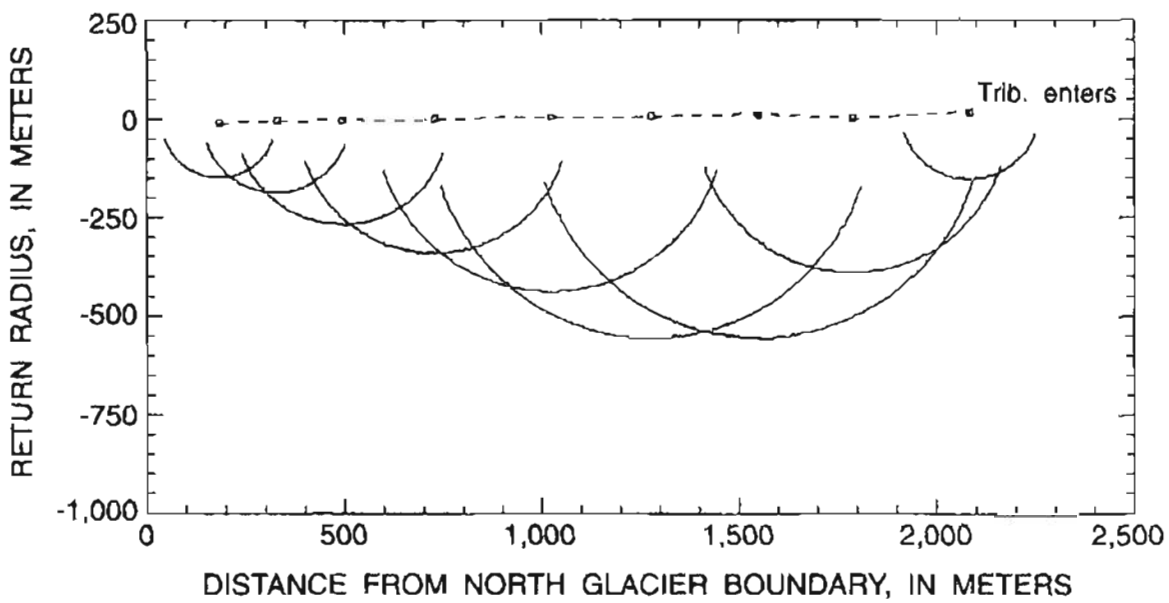
COORDINATE SYSTEMS

Local Coordinate System and Survey Monuments

Geodetic surveys made at Black Rapids Glacier with theodolites and electronic distance measuring equipment are reported in a local coordinate system. This reference grid appears on the base map as the X and Y coordinates (fig. 2). The local coordinate system is an arbitrary rectilinear grid with its horizontal scale at sea level. Its origin is located approximately at UTM Easting 516,000 m, and Northing 7,026,000 of Zone 6. The local grid is also approximately parallel with UTM Zone 6. The 33 monuments in the basin were surveyed carefully to establish a high order of internal consistency. A survey to tie the net to the UTM grid has not been made; however, altitudes at Black Rapids Glacier are controlled by a survey between monument Rubble and VABM Rapids. A survey done in 1992 using Global Positioning System (GPS) equipment establishes a preliminary tie between the local system and the UTM system.

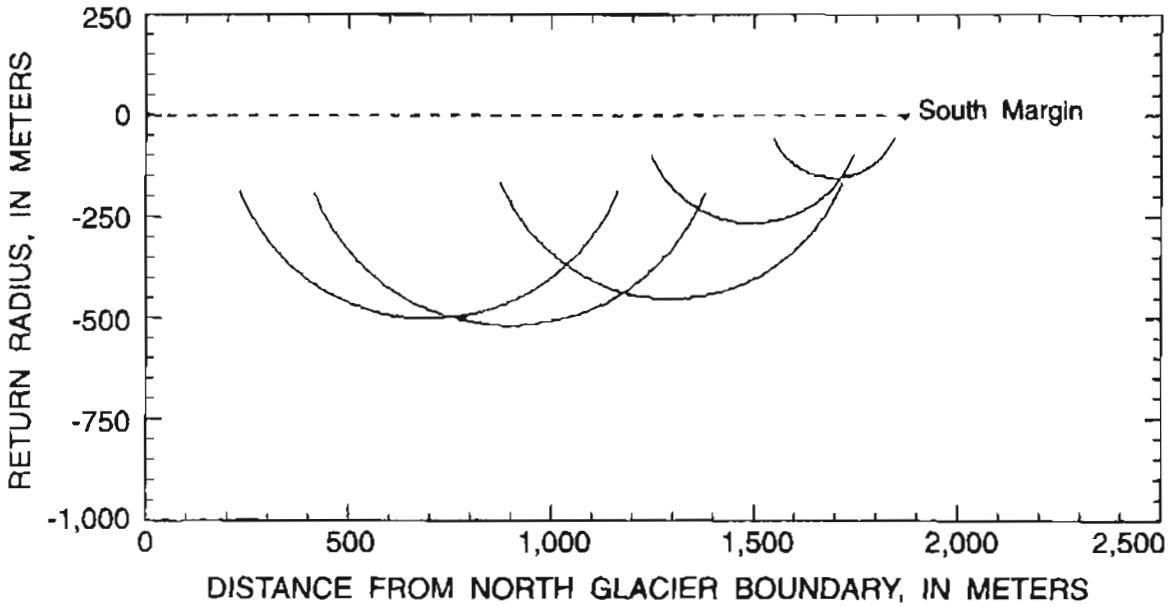


A. Ice radar cross profile--14 km, May 23, 1990

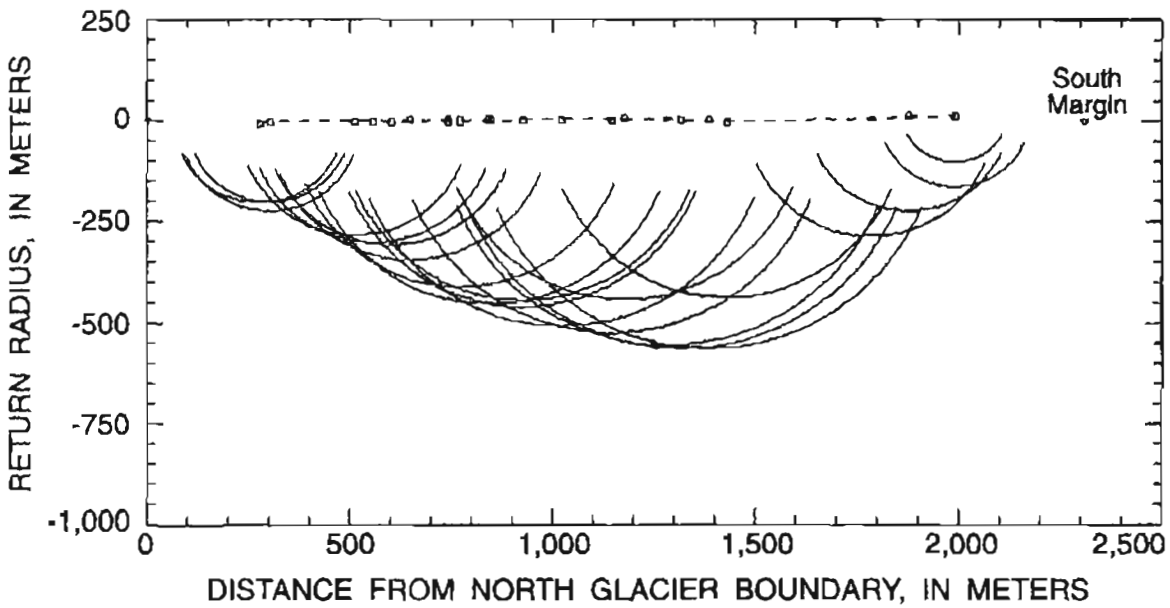


B. Ice radar cross profile--15 km, May 23, 1990

Figure 10. Ice-radar profiles, Black Rapids Glacier.

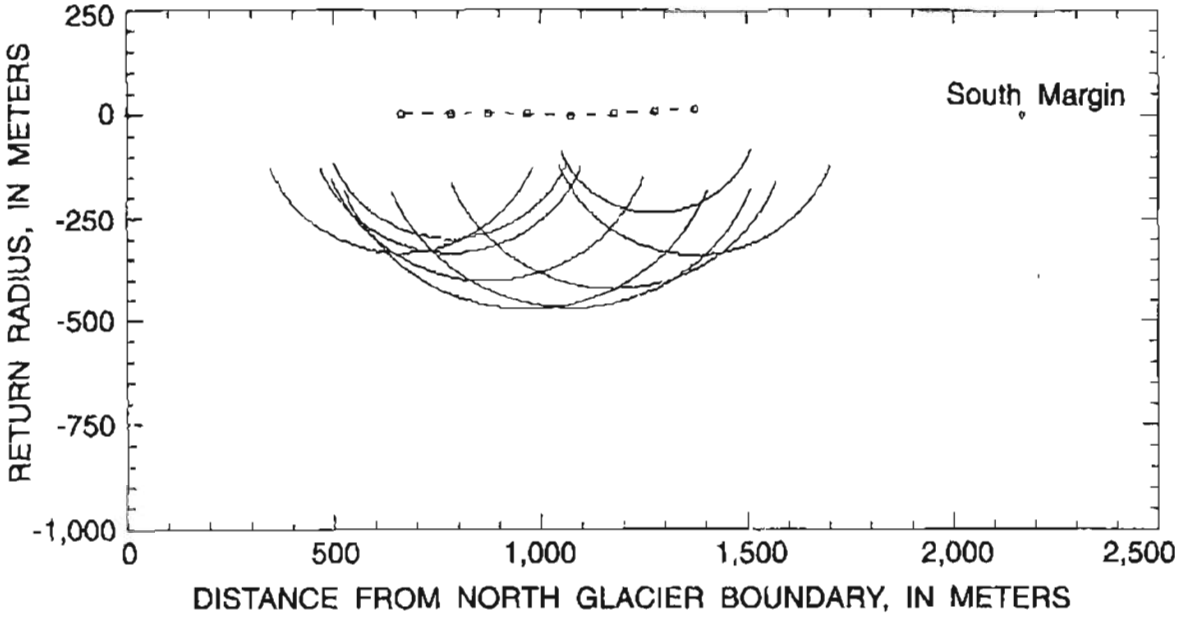


C. Ice radar cross profile--20 km, May 26 ,1990

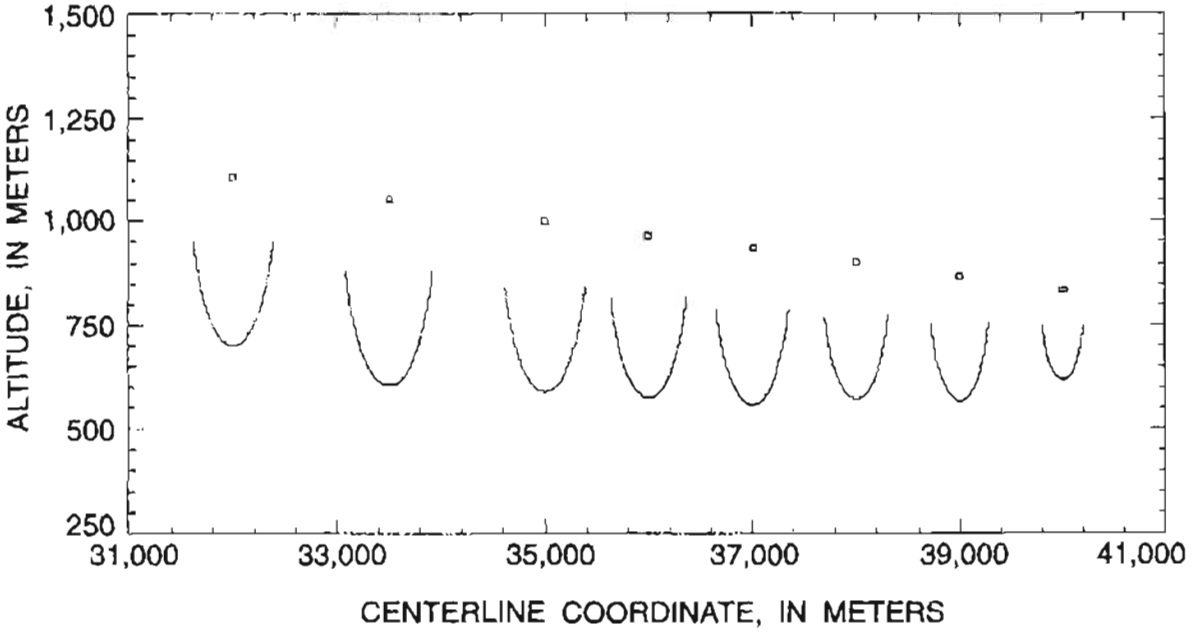


D. Ice radar cross profile--25.9 km, March 21, 1976

Figure 10. Continued.



E. Ice radar cross profile--34.4 km, March 23, 1976



F. Ice radar longitudinal profile--32 to 40 km, April 22, 1987

Figure 10. Continued.

The locations of the monuments within the local coordinate system were established by surveying with theodolites and by measuring distances electronically with a microwave frequency device. Horizontal and vertical angles were measured multiple times and averaged. Distances were measured between redundant monument pairs. The net was calculated by least squares network adjustment (Sikonia, 1977.) Unfortunately, in the 15 years between Sikonia's network computation and the preparation of this report, the original output and results from the network adjustment program have been lost and cannot be reproduced without major effort. The monument coordinates are available, but not the calculated uncertainties. Monument coordinates are listed in table 18 (p. 97).

Even though the local coordinate system is not rigorously tied to UTM, the local grid was approximately lined up with the UTM grid and the following conversions can be used to approximately convert between UTM and local coordinates (Mayo and others, 1979):

$$\text{UTM Easting} = 0.999618*X + 516{,}000 \quad (1)$$

$$\text{UTM Northing} = 0.999618*Y + 7{,}026{,}000 \quad (2)$$

where X and Y are the local sea-level coordinates in meters. It is important to keep in mind that the UTM coordinates derived from these equations from the current local net are more than 100 m in error. In May 1992, a field crew from the University of Alaska made GPS measurements of several points in the basin to compare the arbitrary local coordinate system to UTM (North American Datum 1927). Two monuments were surveyed: Lake and Potholes (table 19, p. 97). Assuming the local coordinate system is internally consistent, it can be rotated, translated, and scaled to a better approximation of the UTM grid. The transformation between the local (untied) system and the GPS derived system is based on the two observations in table 19.

We transformed the coordinate pairs between Lake

[local net, table 18, (14557.92, 14664.43)] ↔ [GPS-derived, table 19, (14440.10, 14635.39)] and Potholes (4959.20, 12811.29) ↔ (4841.13, 12788.72).

To convert between local coordinates and GPS-derived coordinates, use:

$$X = (s \cos \theta)X' - (s \sin \theta)Y' + c \quad (3)$$

$$Y = (s \sin \theta)X' + (s \cos \theta)Y' + d \quad (4)$$

where X, Y, X', and Y' are local (not UTM) coordinates, s is the scale change between the two local systems, θ is the angle of rotation, and c and d are the translations (Moffitt and Bouchard, 1987, p. 315). For the transformation from local (X',Y') to GPS-derived coordinates (X, Y), $s = 0.99989965$, $\theta = -0.03747908°$, $c = -125.9514$, and $d = -18.0427$. To go from GPS-derived (X',Y') to local coordinates (X,Y), $s = 1.00010036$, $\theta = 0.037479085°$, $c = 125.9522$, and $d = 18.1269$.

A more rigorous set of GPS observations must be made before we will transform our local network coordinates. The University of Alaska observations are reported here so that if the more thorough GPS survey is never made, future studies will have this initial transformation to use as a starting point. The GPS measurements should be considered preliminary.

As a preliminary check on the transformation, three of the index stakes that were surveyed with GPS can be compared with geodetic surveys made within the local net (table 20, p. 98) 4 or 5 days after the GPS surveys. Some displacement caused by ice motion occurred during the interval between the surveys.

Centerline Coordinate System

A second coordinate system in use on Black Rapids Glacier is the centerline coordinate system (fig. 2, table 21, p. 98). This curvilinear, longitudinal system defines points at one kilometer intervals (horizontal distance) approximately along the glacier centerline. The origin (0 km) is at the summit of a small rock knob at the head of the glacier. This coordinate system is useful for dynamics calculations and for quick reference to locations along the glacier. The index sites are located at points defined by the centerline coordinate system.

The centerline coordinates for the Loket tributary originate at the 26-km centerline point on the main branch of the glacier. They are defined every kilometer up-glacier from that point. The Loket centerline coordinates are prefaced with an "L" to distinguish them from the coordinates along the main ice stream.

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TABLES 1-21

Table 1. Net mass balance data, Black Rapids Glacier

[Results are given in meters of water equivalent. This table is condensed from table 2, which contains the field data and computation details. km, kilometers; ---, no data.]

Balance year	Net mass balance, Black Rapids Glacier site									
	2 km	4 km	8 km	14 km	20 km	26 km	32 km	38 km	L-19 km	L-22 km
1972	---	---	---	---	-2.76	---	-4.25	---	---	---
1973	---	---	---	-0.77	-2.09	-4.08	-4.65	---	---	---
1974	1.82	0.52	-0.16	-1.95	-3.63	-4.28	---	---	---	---
1975	---	1.20	0.44	-0.55	-2.40	-3.12	-4.42	-5.42	---	---
1976	---	1.38	0.72	-1.09	-3.01	-3.20	-4.79	---	---	---
1977	2.47	1.87	0.93	-0.51	-2.09	-3.00	-4.45	-6.02	---	-1.56
1978	---	1.10	0.34	-1.38	-3.17	-3.71	-5.13	-6.06	---	-2.64
1979	---	0.92	0.06	-1.98	---	-4.20	---	-6.87	---	---
1980	---	2.25	0.93	-0.10	-1.98	-3.16	-3.97	-6.21	0.53	-1.35
1981	3.22	1.87	0.89	-0.19	-2.23	-4.13	-4.90	-6.49	0.29	-1.85
1982	---	1.19	0.46	-0.97	-2.74	-4.14	-5.01	-6.26	-0.54	-2.37
1983	---	1.57	0.16	-0.86	-2.36	-3.20	-4.05	-5.62	-0.55	-2.06
1984	---	1.18	0.67	-0.60	-2.32	-3.78	-4.36	-5.97	-0.22	-1.79
1985	---	1.62	0.97	0.13	-2.14	-3.08	-3.95	-5.29	0.23	-1.42
1986	---	1.78	0.71	-0.46	-2.65	-4.34	-4.42	-6.29	-0.83	-2.26
1987	---	---	0.20	-0.75	-2.77	-4.49	-4.24	-5.88	0.13	-1.23
1988	---	---	0.41	-0.75	-2.13	-4.33	-3.55	---	---	-2.47
1989	---	---	0.91	-1.40	---	-4.02	---	-5.71	---	---
1990	---	---	1.95	-1.67	-3.25	---	---	---	---	---
1991	---	---	0.69	-0.69	-2.62	---	---	---	---	---
1992	---	---	0.78	-0.89	-2.24	---	---	---	---	---

Table 2A. Mass balance, 2 km site, Black Rapids Glacier

[m/d/y, month/day/year, b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter, d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'. Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error; Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed, b(i), ice balance, b(f), firn balance; b(s), snow balance; b(k), internal accumulation--rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985), b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e	n	Est.	Obsv.	Est			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	materia	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1974 BALANCE YEAR:																						
STAKE 74-1.5 (installed 3/27/74)																						
3/27/74	5.15	Snow				2.90	1	Snow	2.90		1	0.32	2.25							0.93		0.93
7/22/74	5.43	Snow			0.20			Snow	.20		1	.30	5.23							.06		
								Firn	2.98		1	.51							1.52		0.30	1.82
RESULTS FOR 1974 BALANCE YEAR																			1.52		.30	1.82
DATA FOR 1975 BALANCE YEAR:																						
STAKE 75-1.6 (installed 2/28/75)																						
2/28/75	6.00	Snow				3.98	6	Snow	3.98	0.01	6	0.39	2.02							1.55		1.55
8/28/75	5.41	Snow																				
RESULTS FOR 1975 BALANCE YEAR.																						no results
RESULTS FOR 1976 BALANCE YEAR (no data)																						no results
DATA FOR 1977 BALANCE YEAR																						
STAKE 77-2 (installed 3/18/77)																						
3/18/77	5.90	Snow				6.00	2	Snow	6.00	0.00	2	0.39	- .10							2.34		2.34
9/23/77	5.81	Snow				1.49	6	Snow	1.49	.00	6	.28	4.32							42		
								Firn	4.42		1	.51							2.26		0.21	2.47
RESULTS FOR 1977 BALANCE YEAR:																			2.26		21	2.47
DATA FOR 1978 BALANCE YEAR:																						
77-2 (continued)																						
3/22/78	8.71	Snow	4.39					Snow	4.39		1	0.39		4.32						1.71		1.71
RESULTS FOR 1978 BALANCE YEAR:																						no results
RESULTS FOR 1979 BALANCE YEAR (no data)																						no results
DATA FOR 1980 BALANCE YEAR:																						
STAKE 80-2 (installed 3/27/80)																						
3/27/80	3.50	Snow			no snow depth measured																	
9/4/80	4.88	Snow			0.63			Snow	0.63		1	0.25	4.05							0.16		
RESULTS FOR 1980 BALANCE YEAR:																						no results
DATA FOR 1981 BALANCE YEAR:																						
80-2 (continued)																						
3/22/81	7.72	Snow	3.67					Snow	3.67		1	0.39		4.05						1.43		1.43
9/10/81	11.16	Snow	1.25					Snow	1.25		1	.40		9.91						50		
								Firn	5.86		1	51							2.99		.23	3.22
3/24/82	14.51	Snow				4.60	3	Snow	4.60		3	.39	9.91							1.79		
RESULTS FOR 1981 BALANCE YEAR:																			2.99		23	3.22

Table 2A, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations		Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b's		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	materia	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)
DATA FOR 1982 BALANCE YEAR:																						
80-2 (continued)																						
3/24/82	14.51	Snow				4.60	3	Snow	4.60	0.05	3	0.39	9.91							1.79		1.79
9/10/82	14.13	Snow				no snow depth measured																
STAKE 82-2 (installed 3/24/82)																						
3/24/82	6.00	Snow				4.60	3	Snow	4.60	.05	3	.39	1.40							1.79		1.79
9/10/82	6.06	Snow				no snow depth measured																
RESULTS FOR 1982 BALANCE YEAR:																						no results
DATA FOR 1983 BALANCE YEAR.																						
STAKE 83-2 (installed 4/23/83)																						
4/23/83	4.73	Snow				no snow depth measured																
9/18/83	4.95	Snow				no snow depth measured																
RESULTS FOR 1983 BALANCE YEAR:																						no results
DATA FOR 1984 BALANCE YEAR																						
STAKE 84-2A (installed 3/16/84)																						
3/16/84	4.38	Snow				no snow depth measured																
8/28/84	4.63	Snow				no snow depth measured																
STAKE 84-2B (installed 3/16/84)																						
3/16/84	4.62	Snow				no snow depth measured																
8/28/84	4.81	Snow				no snow depth measured																
RESULTS FOR 1984 BALANCE YEAR:																						no results
DATA FOR 1985 BALANCE YEAR.																						
STAKE 85-2 (installed 4/4/85)																						
4/1/85	4.49	Snow				no snow depth measured																
RESULTS FOR 1985 BALANCE YEAR:																						no results

Table 2B. Mass balance, 4 km site, Black Rapids Glacier

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter; d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error; Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed; b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation--rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firm	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1973 BALANCE YEAR:																						
STAKE 73-4 (installed 7/19/73)																						
7/19/73	4.78	Snow		snow depth not measured																		
10/24/7	5.75	Snow	1.03					Snow	1.03		1	0.40		4.72						0.41		0.41
3/27/74	6.65	Snow		0.32	1.93			Snow	1.93		1	.32	4.72							.62		
RESULTS FOR 1973 BALANCE YEAR:																						no results
DATA FOR 1974 BALANCE YEAR																						
STAKE 73-4 (continued)																						
10/24/7	5.75	Snow	1.03					Snow	1.03		1	0.40		4.72						0.41		0.41
3/27/74	6.65	Snow		0.32	1.93			Snow	1.93		1	.32	4.72							.62		.62
7/22/74	5.91	Snow	.79					Snow	.79		1	.20		5.12						.16		
								Firm	.40		1	.51							.21		.31	.52
2/28/75	8.88	Snow		.39	3.68	3.78	3	Snow	3.76	0.04	4	.39	5.12							1.47		
RESULTS FOR 1974 BALANCE YEAR:																			.21		.31	.52
DATA FOR 1975 BALANCE YEAR.																						
STAKE 73-4 (stake not found on 2/28/75; b' calculated using 75-4 data)																						
2/28/75	8.88	Snow		0.39	3.68	3.78	3	Snow	3.76	0.04	4	0.39	5.12							1.47		1.47
8/28/75	7.13	Snow	0.02	20				Snow	.02		1	.20		7.11						00		
								Firm	1.99		1	.51							1.01		0.19	1.20
3/23/76	11.06	Snow				3.95		Snow	3.95	.01	6	.38	7.11							1.50		
STAKE 75-4 (installed 2/28/75)																						
2/28/75	7.60	Snow		.39	3.68	3.78	3	Snow	3.76	.04	4	.39	3.84							1.47		1.47
8/28/75	5.85	Snow	02	20				Snow	.02		1	.20		5.83						00		
								Firm	1.99		1	.51							1.01		.19	1.20
RESULTS FOR 1975 BALANCE YEAR: (average of stakes 73-4 and 75-4)																			1.01		.19	1.20
DATA FOR 1976 BALANCE YEAR																						
STAKE 73-4 (continued)																						
8/28/75	7.13	Snow	0.02					Snow	0.02		1	0.20		7.11						0.00		0.00
3/23/76	11.06	Snow				3.95	6	Snow	3.95	01	6	.38	7.11							1.50		1.50
9/13/76	9.71	Snow						Snow	35		1	.26		9.36						.09		
								Firm	2.25		1	.51							1.15		.27	1.42
Note: Snow depth not measured on 9/13/76. d(s) estimated from 8 km data																						
STAKE 75-4 (stake not found on 3/23/76)																						
8/28/75	5.85	Snow	02	.20				Snow	.02		1	.20		5.83						.00		.00
9/13/76	8.30	Snow		.26				Snow	.35		1	26		7.95						.09		
								Firm	2.12		1	.51							1.08		.27	1.35
Note: Snow depth at stake 75-4 on 8/28/75 inferred from measurements at stake 73-4.																						
Note: Snow depth not measured on 9/13/76 d(s) estimated from 8 km data																						
RESULTS FOR 1976 BALANCE YEAR: (average of stakes 73-4 and 75-4)																			1.11		.27	1.38
DATA FOR 1977 BALANCE YEAR:																						
STAKE 77-4 (installed 3/18/77)																						
3/18/77	5.96	Snow				5.38	3	Snow	5.38	0.01	3	0.38	0.58							2.05		2.05
9/23/77	5.00	Snow				1.16	10	Snow	1.16	.01	10	.33	3.84							.38		
								Firm	3.27		1	.51							1.67		0.20	1.87
RESULTS FOR 1977 BALANCE YEAR:																			1.67		.20	1.87

Table 2B, continued

Observations							Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b's		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
									DATA FOR 1978 BALANCE YEAR:													
STAKE 77-4 (continued)																						
9/23/77	5.00	Snow				1.16	10	Snow	1.16	0.01	10	0.33	3.84							0.38		0.38
3/18/78	7.22	Snow				3.41	5	Snow	3.41	.00	5	.36	3.81							1.23		1.23
7/28/78	6.00	Snow	2.19					Snow	2.19		1	.40		3.81						.88		.88
10/23/7	6.99	Snow	6.99			1.50	2	Snow	1.50	.00	2	.40	5.49							.60		
								Firn	1.68		1	.51							.86		.24	1.10
RESULTS FOR 1978 BALANCE YEAR																			.86		.24	1.10
									DATA FOR 1979 BALANCE YEAR:													
STAKE 77-4 (continued)																						
10/23/7	6.99	Snow				1.50	2	Snow	1.50	0.00	2	0.40	5.49							0.60		0.60
3/28/79	8.82	Snow				3.65	10	Snow	3.65	.03	10	.36	5.17							1.31		1.31
8/23/79	8.35	Snow			0.01			Snow	.01		1	.36	6.34							.00		
								Firn	1.17		1	.51							0.60		0.28	.88
STAKE 79-4 (installed 3/28/79)																						
3/28/79	8.21	Snow				3.65	10	Snow	3.65	.03	10	.36	4.56							1.31		1.31
8/23/79	5.93	Snow			.01			Snow	.01		1	.20	5.92							.00		
								Firn	1.36		1	.51							.69		.28	.97
RESULTS FOR 1979 BALANCE YEAR: (average of stakes 77-4 and 79-4)																			.64		.28	.92
									DATA FOR 1980 BALANCE YEAR:													
STAKE 79-4 (stake not found on 3/27/80)																						
8/23/79	5.93	Snow			.01			Snow	.01		1	.20	5.92							.00		.00
9/04/80	10.26	Snow			.45			Snow	.45		1	.20	9.81							.09		
								Firn	3.89		1	.51							1.98		.28	2.26
STAKE 80-4 (installed 3/27/80)																						
3/27/80	4.66	Snow				4.99	4	Snow	4.99	.04	4	.36	- .33							1.80		1.80
9/04/80	3.96	Snow			.45			Snow	.45		1	.30	3.51							.14		
								Firn	3.84		1	.51							1.96		.28	2.24
RESULTS FOR 1980 BALANCE YEAR: (average of stakes 79-4 and 80-4)																			1.97		.28	2.25
									DATA FOR 1981 BALANCE YEAR:													
STAKE 80-4 (continued)																						
9/04/80	3.96	Snow			0.45			Snow	0.45		1	0.30	3.51							0.14		0.14
3/22/81	6.87	Snow	3.36					Snow	3.36		1	.36		3.51						1.21		1.21
9/10/81	7.32	Snow			.50			Snow	.50		1	.30	6.82							.15		
						3.21	4	Firn	3.21	.01	4	.51	3.61	<==1980 s.s.					1.64		0.23	1.87
RESULTS FOR 1981 BALANCE YEAR:																			1.64		.23	1.87
									DATA FOR 1982 BALANCE YEAR:													
STAKE 80-4 (continued)																						
9/10/81	7.32	Snow			0.50			Snow	0.50		1	0.30	6.82							0.15		0.15
3/24/82	10.02	Snow				3.56	10	Snow	3.56	0.02	10	.36	6.46							1.28		1.28
9/10/82	8.84	Snow			.40			Snow	.40		1	.30	8.44							.12		
						1.82	10	Firn	1.82	.03	10	.51	8.62	<==1981 s.s					.93		.26	1.19
STAKE 82-4 (installed 3/23/82)																						
3/24/82	4.18	Snow				3.56	10	Snow	3.56	.02	10	.36	62							1.28		1.28
9/10/82	3.03	Snow			.40			Snow	.40		1	.30	2.63							.12		
						1.82	10	Firn	1.82	.03	10	.51	.81	<==1981 s.s					.93		.26	1.19
RESULTS FOR 1982 BALANCE YEAR.																			.93		.28	1.19

Table 2B, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ		b'ss		Material	Change	ρ	Ice	Firm	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e	n	Est		Obsv.	Est			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	(g/cm³)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)
								DATA FOR 1983 BALANCE YEAR:															
STAKE 82-4 (continued)																							
9/10/82	3.03	Snow			0.40			Snow	0.40		1	0.30		2.63							0.12		0.12
4/23/83	6.25	Snow				3.88	7	Snow	3.88	.03	7	.36		2.37							1.40		1.40
9/18/83	5.36	Snow			.40			Snow	.40		1	.30		4.96							.12		
								Firn	2.59			.51								1.32		0.25	1.57
RESULTS FOR 1983 BALANCE YEAR:																				1.32		.25	1.57
								DATA FOR 1984 BALANCE YEAR:															
STAKE 82-4 (continued)																							
9/18/83	5.36	Snow			0.40			Snow	0.40		1	0.30		4.96							0.12		0.12
3/16/84	8.06	Snow	3.10					Snow	3.10		1	.36			4.96						1.12		1.12
STAKE 84-4A (installed 3/16/84)																							
3/16/84	6.15	Snow	3.10					Snow	3.10		1	.36		3.05							1.12		1.12
8/28/84	5.34	Snow	.58					Snow	.58		1	.30			4.76						.17		
								Firn	1.71		1	.51								.87		.25	1.12
4/4/85	8.56	Snow				3.80	5	Snow	3.80	.01	5	.36		4.76							1.37		
STAKE 84-4B (installed 3/16/84)																							
3/16/84	6.33	Snow	3.10					Snow	3.10		1	.36		3.23							1.12		1.12
8/28/84	5.59	Snow	.42					Snow	.42		1	.30			5.17						.13		
								Firn	1.94		1	.51								.99		.25	
4/4/85	8.97	Snow				3.80	5	Snow	3.80	.01	5	.36		5.17							1.37		
RESULTS FOR 1984 BALANCE YEAR: (average of stakes 84-4A and 84-4B)																				.93		.25	1.18
								DATA FOR 1985 BALANCE YEAR:															
STAKE 84-4A (continued)																							
8/28/84	5.34	Snow	0.58					Snow	0.58		1	0.30			4.76						0.17		0.17
4/4/85	8.56	Snow				3.80	5	Snow	3.80	.01	5	.36		4.76							1.37		1.37
9/12/85	8.08	Snow			0.72			Snow	.72		1	.30		7.36							.22		
								Firn	2.60		1	.51			4.76					1.33		0.33	1.66
STAKE 84-4B (continued)																							
8/28/84	5.59	Snow	.42					Snow	.42		1	.30			5.17						.13		
4/4/85	8.97	Snow				3.80	5	Snow	3.80	.01	5	.36		5.17							1.37		1.37
9/12/85	8.33	Snow			.72			Snow	.72		1	.30		7.61							.22		
								Firn	2.44		1	.51			5.17					1.24		.33	1.57
RESULTS FOR 1985 BALANCE YEAR: (average of stakes 84-4A and 84-4B)																				1.29		.33	1.62

Table 2B, continued

Observations								Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s e	n	Est.	Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1986 BALANCE YEAR.																						
STAKE 84-4A (continued)																						
9/12/85	8.08	Snow			0.72			Snow	0.72		1	0.30	7.36							0.22		.22
4/3/86	10.77	Snow				3.80	5	Snow	3.80	0.03	5	.36	6.97							1.37		1.37
9/25/86	10.42	Snow			.45			Snow	.45		1	.30	9.97							.14		
								Firn	3.00		1	.51							1.53		0.27	1.80
STAKE 84-4B (continued)																						
9/12/85	8.33	Snow			.72			Snow	.72		1	.30	7.61							.22		
4/3/86	11.24	Snow				3.80	5	Snow	3.80	.03	5	.36	7.44							1.37		1.37
9/25/86	10.72	Snow			.46			Snow	.45		1	.30	10.27							.14		
								Firn	2.83		1	.51							1.44		.27	1.71
STAKE 86-4 (installed 4/3/86)																						
4/3/86	6.14	Snow				3.80	5	Snow	3.80	.03	5	.36	2.34							1.37		1.37
9/25/86	5.83	Snow			.45			Snow	.45		1	.30	5.38							.14		
								Firn	3.04		1	.51							1.55		.27	1.82
RESULTS FOR 1986 BALANCE YEAR (average of 84-4A, 84-4B, and 86-4)																			1.51		.27	1.78
DATA FOR 1987 BALANCE YEAR.																						
STAKE 86-4 (continued)																						
9/25/86	5.83	Snow			0.45			Snow	0.45		1	0.30	5.38							0.14		0.14
3/18/87	9.64	Snow	4.26					Snow	4.26		1	.36		5.38						1.53		1.53
STAKE 87-4 (installed 3/18/87)																						
3/18/87	7.02	Snow	4.26					Snow	4.26		1	.36		2.76						1.53		1.53
RESULTS FOR 1987 BALANCE YEAR																						no results

Table 2C. Mass balance, 8 km site, Black Rapids Glacier

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters, ρ, density; g/cm³, grams per cubic centimeter, d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b', Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations, s.e., standard error; Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed; b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation–rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup ice, superimposed ice]

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ		b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.		Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1973 BALANCE YEAR:																							
STAKE 73-8.0 (installed 7/22/73)																							
7/23/73	1.50	Snow																					
10/24/73	2.10	Snow				0.90	1	Snow	0.90		1	0.25		1.20							0.22		
3/27/74	2.74	Snow				1.40	1	Snow	1.40		1	.36		1.34							.50		
STAKE 73-8.7-F (installed 10/27/73)																							
10/27/73	1.60	Snow		0.25	0.79			Snow	.79		1	.25		0.81							.19		
3/27/74	2.30	Snow				1.40	1	Snow	1.40		1	.36		0.90							.50		
RESULTS FOR 1973 BALANCE YEAR:																							no results
DATA FOR 1974 BALANCE YEAR:																							
STAKE 73-8.7-F																							
3/27/74	2.30	Snow				1.40	1	Snow	1.40		1	0.36		0.90							0.50		0.50
7/22/74	1.14	Snow			0.35			Snow	.35		1	.51		0.79							.18		.18
STAKE 74-8.7-F (installed 7/22/74)																							
7/22/74	5.19	Snow			.35			Snow	.35		1	.51		4.84							.18		.18
2/28/75	6.25	Snow				2.45	3	Snow	2.45	0.02	3	.33		3.60		Firn	-1.04	#REF!		#REF!	.81	.31	#REF!
STAKE 73-8.0																							
3/27/74	2.74	Snow				1.40	1	Snow	1.40		1	.36		1.34							.50		.50
7/22/74	1.55	Snow			.35			Snow	.35		1	.51		1.20							.18		.18
STAKE 74-8.0 (installed 3/27/74)																							
3/27/74	5.01	Snow				1.40	1	Snow	1.40		1	.36		3.61							.50		.50
7/22/74	3.85	Snow			.35			Snow	.35		1	.51		3.50							.18		.18
2/28/75	5.10	Snow				2.52	6	Snow	2.52		6	.33		2.58		Firn	- .92	51		- .47	.83	.31	- .16
RESULTS FOR 1974 BALANCE YEAR; (from 74-8.0, stake closest to index site)																				- .47		.31	- .16
DATA FOR 1975 BALANCE YEAR:																							
STAKE 74-8.0																							
2/28/75	5.10	Snow				2.52	6	Snow	2.52	0.02	6	0.33		2.58							0.83		0.83
8/28/75	3.28	Snow		0.51	0.78			Snow	.78		1	.51		2.50							.40	0.20	.60
Note. 1975 summer surface not yet formed on 8/28/75.																							
3/24/76		Snow		.33	2.83	2.85	7	Snow	2.85	.02	7	.33											
								Firn	.51	.48	1				2.98					0.24		.20	.44
Stake height, b', not read on 3/24/76, data from 9/13/76 used to determine b'ss of summer surface.																							
9/13/76	4.13	Snow		.26	.25			Snow	.25		1	.26		3.88							.07		
				.50	.90			Firn	.90		1	.50		2.98	<== 1975 s.s.								
Note: Snow pit dug through 1976 firn accumulation to 1975 summer surface on 9/13/76.																							
RESULTS FOR 1975 BALANCE YEAR:																				.24		.20	.44
DATA FOR 1976 BALANCE YEAR:																							
STAKE 74-8.0 (continued)																							
3/24/76		Snow		0.33	2.83	2.85	8	Snow	2.85	0.02	8	.33									0.94		0.94
Stake height, b', not read on 3/24/76																							
9/13/76	4.13	Snow		.26	.25			Snow	.25		1	0.26		3.88							.07		
				.50	.90			Firn	.90		1	.50		2.98	<== 1975 s.s.					0.45		.27	.72
Note: Snow pit dug through 1976 firn accumulation to 1975 summer surface on 9/13/76.																							
RESULTS FOR 1976 BALANCE YEAR																				.45		.27	.72

Table 2C, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ		b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e	n	Est.		Obsv.	Est.			Est	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	(g/cm³)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)
								DATA FOR 1977 BALANCE YEAR:															
STAKE 74-8.0 (continued)																							
3/18/77	7.40	Snow		0.40	3.69	3.87	4	Snow	3.87	0.02	4	0.40		3.53							1.55		1.55
9/23/77	5.78	Snow		.28	.82	0.77	10	Snow	78	.01	10	28		4.98							22		
								Firn	1.46		1	.51								0.74		0.19	.93
RESULTS FOR 1977 BALANCE YEAR: (from STAKE 74-8)																				.74		.19	.93
								DATA FOR 1978 BALANCE YEAR:															
STAKE 74-8.0 (continued)																							
3/22/78	7.37	Snow		0.36	2.28			Snow	2.28		1	0.36		5.09							0.82		0.82
10/23/78	6.25	Snow				1.12	5	Snow	1.12	0.02	5	26		6.13							.29		
								Firn	04		1	.51								0.02		0.25	27
3/28/79	7.66	Snow				2.57	2	Snow	2.57		2	36		5.09							.93		
STAKE 77-8 (installed 9/23/77)																							
9/23/77	2.63	Snow		.28	82	0.77	9	Snow	0.78	01	10	28		1.85							.22		
3/22/78	4.31	Snow		.36	2.28			Snow	2.28		1	36		2.03							.82		.82
								Firn	.18		1	51								.09		.25	.34
STAKE 78-8 (installed 3/22/78)																							
3/22/78	7.62	Snow		.36	2.28			Snow	2.28		1			5.34							.82		.82
10/23/78	6.80	Snow		.26		1.12	5	Snow	1.12	.02	5			5.68							.29		
								Firn	.34		1	51								.17		.25	.42
3/28/79	8.27	Snow		.36		2.57	2	Snow	2.57		2			5.70							.93		
RESULTS FOR 1978 BALANCE YEAR: (average of stakes 74-8.0, 77-8, and 78-8)																				.09		.25	.34
								DATA FOR 1979 BALANCE YEAR:															
STAKE 74-8.0 (continued)																							
3/28/79	7.66	Snow				2.57	2	Snow	2.57	0.00	2	0.36		5.09							0.93		0.93
3/27/80	7.85	Snow				3.11	5	Snow	3.11	.01	5	.36		4.74		Firn	-0.35	0.51		-0.18		0.27	.09
STAKE 78-8 (installed 3/22/78)																							
3/28/79	8.27	Snow				2.57	2	Snow	2.57	.00	2	.36		5.70							.93		.93
8/23/79	5.48	Snow	0.28					Snow	.28		1	26			5.22	Firn	- .48	.51		- .24		.27	.03
3/27/80	8.33	Snow				3.11	5	Snow	3.11		5	.36		5.22									
RESULTS FOR 1979 BALANCE YEAR: (average of stakes 74-8 and 78-8)																				- .21		.27	.06
								DATA FOR 1980 BALANCE YEAR:															
STAKE 78-8 (continued)																							
3/27/80	8.33	Snow				3.11	5	Snow	3.11	0.01	5	0.36		5.22							1.12		1.12
9/4/80	6.83	Snow			0.32			Snow	.32		1	.26		6.51							.08		
								Firn	1.29		1	51								0.66		0.27	.93
RESULTS FOR 1980 BALANCE YEAR:																				.66		.27	.93
								DATA FOR 1981 BALANCE YEAR:															
STAKE 78-8 (continued)																							
3/22/81	9.05	Snow				2.67	10	Snow	2.67	0.02	10	0.36		6.38							0.96		0.96
6/22/81	8.24	Snow	1.86					Snow	1.86		1	40			6.38						.74		.74
STAKE 81-8 (installed 3/22/81)																							
3/22/81	6.33	Snow				2.67	10	Snow	2.67	02	10	36		3.66							.96		.96
6/22/81	5.50	Snow	1.84					Snow	1.84		1	40			3.66						.74		74
9/10/81	5.52	Snow			0.55			Snow	.55		1	26		4.97							14		
								Firn	1.31		1	.51								0.67		0.22	.89
3/24/82	7.62	Snow				2.70	5	Snow	2.70	.02	5	36		4.93							.97		
RESULTS FOR 1981 BALANCE YEAR:																				.67		.22	.88

Table 2C, continued

Observations							Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv	Est			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)
DATA FOR 1982 BALANCE YEAR																						
STAKE 81-8 (continued)																						
3/24/82	7.62	Snow				2.70	5	Snow	2.70	0.02	5	0.36	4.93							0.97		0.97
9/10/82	5.59	Snow			0.25			Snow	.25		1	.26	5.34							.07		
								Firn	.42		1	.51							0.21		0.25	.46
4/21/83	7.81	Snow				2.30	10	Snow	2.30		10	.36	5.51							.83		
RESULTS FOR 1982 BALANCE YEAR:																			.21		.25	.46
DATA FOR 1983 BALANCE YEAR																						
STAKE 81-8 (continued)																						
4/21/83	7.81	Snow				2.30	10	Snow	2.30		10	0.36	5.51							0.83		0.83
9/8/83	5.70	Snow	0.61					Snow	.61		1	.26		5.09						.16		
								Firn	- .42		1	.51							-0.21		0.23	.02
3/17/84	8.18	Snow				3.07	7	Snow	3.07	0.01	7	.36	5.09							1.11		
STAKE 83-8 (installed 4/21/83)																						
4/21/83	6.17	Snow				2.30	10	Snow	2.30		10	.36	3.87							.83		.83
9/8/83	4.53	Snow	.50					Snow	.50		1	.26		4.03						.13		
								Firn	.16		1	.51							.08		.23	.31
3/17/84	7.10	Snow				3.07	7	Snow	3.07		7	.36	4.03							1.11		
RESULTS FOR 1983 BALANCE YEAR: (average of stakes 81-8 and 83-8)																			- .07		.23	.16
DATA FOR 1984 BALANCE YEAR																						
STAKE 83-8 (continued)																						
3/17/84	7.10	Snow				3.07	7	Snow	3.07	0.01	7	0.36	4.03							1.11		1.11
8/28/84	5.69	Snow			0.81			Snow	.81		1	.26	4.88							.21		
								Firn	.85		1	.51							0.43		0.24	.67
RESULTS FOR 1984 BALANCE YEAR																			.43		.24	.67
DATA FOR 1985 BALANCE YEAR																						
STAKE 83-8 (continued)																						
4/4/85	8.12	Snow				2.74	7	Snow	2.74	0.01	7	0.36	5.38							0.99		0.99
9/11/85	7.06	Snow			0.40			Snow	.40		1	.26	6.66							.10		
								Firn	1.28		1	.51							0.65		0.32	.97
4/3/86	9.20	Snow				2.25	7	Snow	2.25	.01	7	.36	6.95							.81		
RESULTS FOR 1985 BALANCE YEAR:																			.65		.32	.97
DATA FOR 1986 BALANCE YEAR																						
STAKE 83-8 (continued)																						
4/3/86	9.20	Snow				2.25	7	Snow	2.25	0.01	7	0.36	6.95							0.81		0.81
9/25/86	8.06	Snow			0.38			Snow	.38		1	.26	7.68							.10		
					.87			Firn	.87		1	.51	6.81	<==1985 s.s.					0.44		0.27	.71
STAKE 86-8 (installed 4/3/86)																						
4/3/86	5.87	Snow				2.25	7	Snow	2.25	.01	7	.36	3.62							.81		.81
9/25/86	4.71	Snow			.38			Snow	.38		1	.26	4.33							.10		
					.87			Firn	.87		1	.51	3.46	<==1985 s.s.					.44		.27	.71
3/18/87	7.19	Snow				3.00	1	Snow	3.00		1	.44	4.19							1.32		
RESULTS FOR 1986 BALANCE YEAR:																			.44		.27	.71

Table 2C, continued

Observations							Accumulation calculations						Summer surface		Ablation calculations		Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material Change	ρ	Ice	Firm	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv.	Est.		Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)	(m)	(g/cm³)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)
									DATA FOR 1987 BALANCE YEAR												
STAKE 86-8 (continued)																					
3/18/87	7.19	Snow				3.00	1	Snow	3.00		1	0.44	4.19						1.32		1.32
8/27/87	5.32	Snow				1.31	4	Snow	1.31		4	.51	4.01						.67		
								Firn	-.18		1	.51						-0.09		0.29	.20
4/21/88	8.54	Snow	4.53					Snow	4.53		1	.36		4.01					1.63		1.63
RESULTS FOR 1987 BALANCE YEAR																		-.09		.29	.20
									DATA FOR 1988 BALANCE YEAR												
STAKE 86-OZONE																					
4/21/88	7.78	Snow	4.53					Snow	4.53		1	0.36	3.25						1.63		1.63
9/2/88	3.83	Snow			0.22			Snow	.22		1	.25	3.61								
								Firn	.35		1	.51						0.18		0.23	0.41
4/19/89	6.10	Snow			2.77			Snow	2.77		1	.36	3.33						1.00		
RESULTS FOR 1988 BALANCE YEAR																		.18		.23	.41
									DATA FOR 1989 BALANCE YEAR:												
STAKE 86-8 (continued)																					
4/19/89	6.86	Snow			2.77			Snow	2.77		1	0.36	4.09						1.00		1.00
4/22/90	9.77	Snow			4.40			Snow	4.40		1	.36	5.37						1.58		
								Firn	1.28		1	.51						0.65		0.26	0.91
Stake 86-8 was not read on 4/19/89. Its b' was calculated using data from stake 86-OZONE.																					
RESULTS FOR 1989 BALANCE YEAR																		.65		.26	.91
									DATA FOR 1990 BALANCE YEAR.												
STAKE UA90-8 (installed 4/19/90)																					
4/19/90	6.10	Snow			4.40			Snow	4.40		1	0.36	1.70						1.58		1.58
7/15/90	7.01	Snow	5.32					Snow	5.32		1	.40		1.70					2.13		2.13
5/1/91	7.99	Snow				2.99	10	Snow	2.99	0.02	10	.36	5.00						1.07		
								Firn	3.30		1	.51						1.69		0.26	1.95
RESULTS FOR 1990 BALANCE YEAR																		1.69		.26	1.95
									DATA FOR 1991 BALANCE YEAR.												
STAKE UA90-8 (continued)																					
5/1/91	7.99	Snow				2.99	10	Snow	2.99	0.02	10	0.36	5.00						1.07		1.07
5/4/92	9.10	Snow				3.27	10	Snow	3.27	.06	10	.36	5.84						1.18		
								Firn	0.84		1	.51						0.43		0.26	0.69
RESULTS FOR 1991 BALANCE YEAR																		.43		.26	.69
									DATA FOR 1992 BALANCE YEAR.												
STAKE UA90-8 (continued)																					
5/4/92	9.10	Snow				3.27	10	Snow	3.27	0.06	10	0.36	5.84						1.18		1.18
9/23/92	7.36	Snow				.49	10	Snow	.49	.01	10	.26	6.87						.13		
								Firn	1.03		1	.51		5.84				0.53		0.25	.78
RESULTS FOR 1992 BALANCE YEAR:																		.53		.25	.78

Table 2D. Mass balance, 14 km site, Black Rapids Glacier

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter, d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface, n, number of observations; s.e., standard error, Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed; b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation--rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations					Summer surface b'ss		Ablation calculations			Mass balance results				
Date	Stake reading b'	Surface material	Stake d(s)	Pit ρ	Pit d(s)	Probe d(s) Mean	Probe d(s) n	Material	Thickness Mean	Thickness s.e.	Thickness n	ρ Est.	Obsv.	Est.	Material	Change	ρ Est.	Ice b(i)	Firn b(f)	Snow b(s)	Internal b(k)	Net b_n
m/d/y	(m)		(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1973 BALANCE YEAR.																						
4/3/73		Snow				2.10	1	Snow	2.10		1	0.34								0.71		0.71
Note: Snow depth reported for 4/3/73 is the mean of probings at 13 and 15 km locations.																						
STAKE 73-14-F (installed 7/20/73)																						
7/20/73	4.90	Sup ice		0.90	0.10			Sup. ice	10			.90	4.80							09		.09
10/25/7	4.70	Snow				.75	5	Snow	75	.02	5	.34	3.95		Ice	-0.85	0.90	-0.77		.26		- .77
RESULTS FOR 1973 BALANCE YEAR:																		- .77				- .77
DATA FOR 1974 BALANCE YEAR:																						
STAKE 73-14-F (continued)																						
3/28/74	5.44	Snow	1.49					Snow	1.49		1	0.34		3.95						0.51		0.51
7/21/74	3.65	Ice											3.65		Ice	-0.30	0.90	-0.27				- .27
3/1/75	4.05	Snow		0.34	2.14	2.28	7	Snow	2.26	.03	8	34	1.79		Ice	-2.16	.90	-1.95		77		-1.95
RESULTS FOR 1974 BALANCE YEAR:																		-1.95				-1.95
DATA FOR 1975 BALANCE YEAR:																						
STAKE 73-14-F (continued)																						
3/1/75	4.05	Snow		0.34	2.14	2.28	7	Snow	2.26	0.03	8	0.34	1.79							0.77		0.77
8/26/75	1.19	Snow						Snow	.02		1	20	1.17		Ice	-0.62	0.90	-0.56		.00		- .56
STAKE 75-14 (installed 3/1/75)																						
3/1/75	9.05	Snow		.34	2.14	2.28	7	Snow	2.26	.03	8	.34	6.79							.77		.77
8/26/75	6.31	Snow			.02			Snow	.02		1	.20	6.29		Ice	- .50	.90	- .45		.00		- .45
3/24/76	8.46	Snow				2.23		Snow	2.23	.01	5	34	6.23		Ice	- .55	.90	- 50		.76		
Note: The net balance result for the year is the average b(i) for the two stakes on 8/26/75 plus the b(i) of stake 75-14 from 8/26/75 to the end of the balance year.																						
RESULTS FOR 1975 BALANCE YEAR: (average of stakes 73-14 and 75-14)																		- 55				- .56
DATA FOR 1976 BALANCE YEAR:																						
STAKE 75-14 (continued)																						
3/24/76	8.46	Snow				2.23	5	Snow	2.23	0.01	5	0.34	6.23							0.76		0.76
9/13/76	5.31	Snow				.27	1	Snow	27		1	20	5.04	4.97	Ice	-1.26	0.90	-1.13		.05		-1.13
3/19/77	8.00	Snow				3.09	3	Snow	3.09	.01	3	34	4.91	4.97						1.05		
STAKE 76-14 (installed 3/24/76)																						
3/24/76	8.10	Snow				2.23	5	Snow	2.23	01	5	.34	5.87							.76		.76
9/13/76	4.92	Snow				.27	1	Snow	.27		1	20	4.65	4.71	Ice	-1.16	.90	-1.04		.05		-1.04
3/19/77	7.87	Snow				3.09	3	Snow	3.09	.01	3	34	4.78	4.71						1.05		
RESULTS FOR 1976 BALANCE YEAR: (average of stakes 75-14 and 76-14)																		-1.09				-1.09
DATA FOR 1977 BALANCE YEAR:																						
STAKE 76-14 (continued)																						
3/19/77	7.87	Snow				3.09	3	Snow	3.09	0.01	3	0.34	4.78	4.71						1.05		1.05
9/23/77	4.80	Snow				.66	10	Snow	.66	.02	10	20	4.15		Ice	-0.57	0.90	-0.51		.13		- .51
RESULTS FOR 1977 BALANCE YEAR.																		- .51				- .51

Table 2D, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ		b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.		Obsv	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1978 BALANCE YEAR:																							
STAKE 76-14 (continued)																							
3/18/78	6.48	Snow	2.34					Snow	2.34		1	0.34			4.15						0.79		0.79
9/24/78	2.82	Snow				.17	10	Snow	.17	02	10	.20		2.65	2.61	Ice	-1.53	0.90	-1.38		.03		-1.38
3/28/79	4.66	Snow		.33	2.11	2.08	5	Snow	2.08	01	6	.33		2.58	2.61						.69		
Note: Temperature record from Gulkana Glacier indicates that melting after 9/24/78 is unlikely.																							
RESULTS FOR 1978 BALANCE YEAR:																			-1.38				-1.38
DATA FOR 1979 BALANCE YEAR:																							
STAKE 76-14 (continued)																							
3/28/79	4.66	Snow			2.11	2.08		Snow	2.08	0.01	5	0.33		2.58	2.61						0.68		0.68
8/23/79	.77	Ice												.77		Ice	-1.64	0.90	-1.66				-1.66
STAKE 79-14 (installed 3/28/79)																							
3/28/79	8.06	Snow			2.11	2.08		Snow	2.08	.01	5	.33		5.98					.00		.68		.68
8/23/79	4.17	Ice												4.17		Ice	-1.81	.90	-1.63				-1.63
3/27/80	6.70	Snow				2.90		Snow	2.90	.00	4	.33		3.80		Ice	-2.18	.90	-1.96		.96		
Note: The net balance result for the year is the average b(i) for the two stakes on 8/23/79 plus the b(i) of stake 79-14 from 8/23/79 to the end of the balance year.																							
RESULTS FOR 1979 BALANCE YEAR:																			-1.98				-1.98
DATA FOR 1980 BALANCE YEAR:																							
STAKE 79-14 (continued)																							
3/27/80	6.70	Snow				2.90	4	Snow	2.90	0.00	4	0.33		3.80							0.96		0.96
9/4/80		Sup. Ice			.04			Sup. Ice	.04		1	.90		3.80							.04		
		Firn			.03			Firn	.03		1	.51								0.02			06
	3.95	Snow				.08	16	Snow	.08	.01	16	.20									.02		
3/22/81	5.90	Snow				2.22	10	Snow	2.22		10	.33		3.68		Ice	-0.12	0.90	-0.10		.73		-.10
RESULTS FOR 1980 BALANCE YEAR:																			-.10				-.10
DATA FOR 1981 BALANCE YEAR:																							
STAKE 79-14 (continued)																							
3/22/81	5.90	Snow				2.22	10	Snow	2.22	0.02	10	0.33		3.68							0.73		0.73
6/22/81	4.82	Snow	1.14					Snow	1.14		1	.40									.46		.46
9/10/81	3.76	Snow				.30	3	Snow	.30	.01	3	.20		3.46		Ice	-0.21	0.90	-0.19		06		-.19
3/25/82	5.52	Snow		.32	2.09	2.06	15	Snow	2.07	01	16	.32		3.46							.66		
RESULTS FOR 1981 BALANCE YEAR:																			-.19				-.19
DATA FOR 1982 BALANCE YEAR:																							
STAKE 79-14 (continued)																							
3/25/82	5.52	Snow		0.32	2.09	2.06		Snow	2.07	0.01	16	.32		3.46							0.66		0.66
9/10/82	2.59	Snow				.11	20	Snow	.11	00	21	.20		2.48		Ice	-0.98	0.90	-0.88		.02		-.88
STAKE 82-14 (installed 3/25/82)																							
3/25/82	8.35	Snow		.32	2.09	2.06		Snow	2.07	.01	16	.32		6.29							.66		.66
9/10/82	5.32	Snow				.11		Snow	.11	.00	20	.20		5.21	5.10	Ice	-1.19	.90	-1.07		.02		-1.07
4/21/83	7.27	Snow		.36	2.10	2.31		Snow	2.29		9	.36		4.98	5.10						.82		
Note: There is no obvious explanation for the 23 cm discrepancy between the fall and spring summer surface measurements.																							
Note: Temperature record from Gulkana Glacier indicates 23 cm of ice melt after 9/10/82 is unlikely.																							
RESULTS FOR 1982 BALANCE YEAR (average of stakes 79-14 and 82-14)																			-.97				-.97

Table 2D, continued

Date	Observations: Stake reading b' (m)	Surface material	Stake d(s) (m)	Pit ρ (g/cm³)	Pit d(s) (m)	Probe d(s) Mean (m)	n	Accumulation calculations: Material	Thickness Mean (m)	s.e. (m)	n	ρ Est. (g/cm³)	Summer surface b's Obsv (m)	Est. (m)	Ablation calculations: Material	Change (m)	ρ Est. g/cm³)	Mass balance results: Ice b(i) (m$_{we}$)	Firn b(f) (m$_{we}$)	Snow b(s) (m$_{we}$)	Internal b(k) (m$_{we}$)	Net b$_n$ (m$_{we}$)
m/d/y																						
DATA FOR 1983 BALANCE YEAR:																						
STAKE 82-14 (continued)																						
4/21/83	7.27	Snow		0.36	2.10	2.31	8	Snow	2.28	0.03	9	0.36	4.99	5.10						0.82		0.82
9/8/83	4.59	Snow				.46	17	Snow	.46	.01	17	.20	4.13	4.18	Ice	-0.92	0.90	-0.83		.09		-.83
3/16/84	6.65	Snow				2.43	10	Snow	2.43	.01	10	.36	4.22	4.18						.87		
STAKE 83-14 (installed 4/21/83)																						
4/21/83	8.09	Snow		.36	2.10	2.31	8	Snow	2.28	.03	9	.36	5.81							.82		.82
9/8/83	5.24	Snow				.46	17	Snow	.46	.01	17	.20	4.78	4.83	Ice	-.98	.90	-.88		.09		-.88
3/16/84	7.30	Snow				2.43	10	Snow	2.43	.01	10	.36	4.87	4.83						.87		
RESULTS FOR 1983 BALANCE YEAR: (average of stakes 82-14 and 83-14)																		-.86				-.86
DATA FOR 1984 BALANCE YEAR:																						
STAKE 82-14 (continued)																						
3/16/84	6.65	Snow				2.43	10	Snow	2.43	0.01	10	0.36	4.22	4.18						0.87		0.87
4/5/85	5.85	Snow				2.38	10	Snow	2.38	.01	10	.36	3.47		Ice	-0.71	0.90	-0.64		.86		-.64
STAKE 83-14 (continued)																						
3/16/84	7.30	Snow				2.43	10	Snow	2.43	.01	10	.36	4.87	4.83						.87		.87
8/28/84	4.39	Snow				.16	4	Snow	.16	.00	4	.20	4.23		Ice	-.60	.90	-.54		.03		-.54
STAKE 84-14 (installed 3/16/84)																						
3/16/84	9.88	Snow				2.43	10	Snow	2.43	.01	10	.36	7.45							.87		.87
8/28/84	6.90	Snow				.16	4	Snow	.16	.00	4	.20	6.74		Ice	-.71	.90	-.64		.03		-.64
4/5/85	9.12	Snow				2.38	10	Snow	2.38	.01	10	.36	6.74							.86		
RESULTS FOR 1984 BALANCE YEAR (average of all three stakes)																		-.60				-.60
DATA FOR 1985 BALANCE YEAR:																						
STAKE 83-14 (continued)																						
9/5/85	4.39	Snow			0.08			Snow	0.08		1	.20	4.31							0.02		
STAKE 84-14 (continued)																						
4/5/85	9.12	Snow				2.38		Snow	2.38	.01	10	.36	6.74							.86		0.86
9/5/85			.09					Sup. Ice	.09		1	.90								08		
				47	.16			Firn	.16		1	.47							0.08			08
	7.07	Snow			.08			Snow	08		1	.20	6.99							.02		
Note: Superimposed ice observed beneath snow and new firn on 9/5/85.																						
4/4/86			.19					Firn	.19		1	70							13			13
	9.16	Snow		.37	2.10	2.25	10	Snow	2.23	.02	11	.37	6.93							.83		
Note: Superimposed ice observed beneath snow and new firn on 4/4/86.																						
RESULTS FOR 1985 BALANCE YEAR																			.13			13
DATA FOR 1986 BALANCE YEAR.																						
STAKE 84-14 (continued)																						
4/4/86	9.16	Snow		0.37	2.10	2.25	10	Snow	2.23	0.02	11	.37	6.93							0.83		0.83
9/25/86	6.80	Snow				.37	10	Snow	.37	.01	10	.20	6.43		Firn	-0.19	0.70		-0.13	07		
															Ice	-.31	.90	-0.28				-.41
STAKE 86-14 (installed 4/4/86)																						
4/4/86	8.07	Snow		.37	2.10	2.25	10	Snow	2.23	.02	11	.37	5.84							.83		.83
9/25/86	5.65	Snow				.37	10	Snow	.37	.01	10	.20	5.28	5.23	Firn	-.19	.70		-.13	.07		
															Ice	-.42	.90	-.38				-.51
3/20/87	7.80	Snow				2.63		Snow	2.63	.02	10	.37	5.17	5.23						97		
RESULTS FOR 1986 BALANCE YEAR (average of stakes 84-14 and 86-14)																		-.33	-.13			-.46
DATA FOR 1987 BALANCE YEAR:																						
STAKE 86-14 (continued)																						

Table 2D, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations				Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ		b'ss		Material	Change	ρ		Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.		Obsv.	Est.			Est.		b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	g/cm³)		(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
3/20/87	7.80	Snow				2.63	10	Snow	2.63	0.02	10	0.37		5.17	5.23							0.97		0.97
8/27/87	4.47	Ice												4.47		Ice	-0.76	0.90		-0.68				-.68
4/21/88	6.97	Snow			2.54			Snow	2.54		1	.37		4.43		Ice	-.80	.90		-.72		.94		-.72
STAKE 87-14 (installed 8/27/87)																								
8/27/87	6.58	Ice												6.58						-.68				
4/21/88	9.01	Snow			2.54			Snow	2.54		1	.37		6.47		Ice		.90		-.78		.94		-.78
RESULTS FOR 1987 BALANCE YEAR:																				-.75				-.75
DATA FOR 1988 BALANCE YEAR:																								
STAKE 86-14 (continued)																								
4/21/88	6.97	Snow			2.54			Snow	2.54		1	0.37		4.43								0.94		0.94
4/15/89	5.49	Snow			1.95			Snow	1.95		1	.37		3.54		Ice	-0.69	0.90		-0.80		.72		-.80
STAKE 87-14 (continued)																								
4/21/88	9.01	Snow			2.54			Snow	2.54		1	.37		6.47								.94		.94
4/15/89	7.64	Snow			1.95			Snow	1.95		1	.37		5.69		Ice	-.78	.90		-.70		.72		-.70
RESULTS FOR 1988 BALANCE YEAR: (average of stakes 86-14 and 87-14)																				-.75				-.75
DATA FOR 1989 BALANCE YEAR:																								
STAKE 87-14 (continued)																								
4/15/89	7.64	Snow			1.95			Snow	1.95		1	0.37		5.69								0.72		0.72
5/25/90	6.83	Snow			2.70			Snow	2.70		1	.37		4.13		Ice	-1.56	0.90		-1.40		1.00		-1.40
RESULTS FOR 1989 BALANCE YEAR:																				-1.40				-1.40
DATA FOR 1990 BALANCE YEAR:																								
STAKE UA90-14(installed 5/25/90)																								
5/25/90	8.71	Snow			2.70			Snow	2.70		1	0.37		6.01								1.00		1.00
5/1/91	6.60	Snow				2.45		Snow	2.45	.02	10	.37		4.15		Ice	-1.86	0.90		-1.67		.91		-1.67
RESULTS FOR 1990 BALANCE YEAR:																				-1.67				-1.67
DATA FOR 1991 BALANCE YEAR:																								
STAKE UA90-14 (continued)																								
5/1/91	6.60	Snow				2.45		Snow	2.45	0.02	10	0.37		4.15								0.91		0.91
5/1/92	6.11	Snow				2.72		Snow	2.72	.01	10	.37		3.39		Ice	-0.76	0.90		-0.69		1.01		-.69
RESULTS FOR 1991 BALANCE YEAR:																				-.69				-.69
DATA FOR 1992 BALANCE YEAR:																								
STAKE UA92-14 (installed 5/1/92)																								
5/1/92	7.91	Snow				2.72		Snow	2.72	0.01	10	0.37		5.19								1.01		1.01
9/23/92	4.75	Snow			0.48	.55		Snow	.55	.01	10	.37		4.20		Ice	-0.98	0.90		-0.89		.20		-.89
RESULTS FOR 1992 BALANCE YEAR:																				-.89				-.89

Table 2E. Mass balance, 20 km site, Black Rapids Glacier

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter, d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'. Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error, Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed, b(i), ice balance; b(f), firn balance; b(s), snow balance, b(k), internal accumulation–rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ		b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mea	n		Mean	s.e.	n	Est.		Obsv	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1972 BALANCE YEAR:																							
STAKE 72-19 (installed 4/24/72, 18.6 km, range line motion site O)																							
4/24/72	7.90	Snow		0.33	1.65	1.53	11	Snow	1.54	0.03	11	0.33		6.36							0.51		0.51
8/3/72	4.58	Ice												4.58		Ice	-1.78	0.90	-1.60				-1.60
STAKE 73-19 (installed 8/3/72, 18.6 km, range line motion site O)																							
8/3/72	4.85	Ice												4.85					-1.60				-1.60
10/19/7	4.20	Snow				68	10	Snow	.68	.02	10	.30		3.52	3.56	Ice	-1.29	.90	-2.76		.20		-2.76
4/3/73	4.83	Snow				1.22	7	Snow	1.22	.07	7	.32		3.61	3.56						.39		
RESULTS FOR 1972 BALANCE YEAR. (at 18.6 km site)																			-2.76				-2.76
DATA FOR 1973 BALANCE YEAR.																							
STAKE 73-19 (continued)																							
4/3/73	4.83	Snow				1.22	7	Snow	1.22	0.07	7	0.32		3.61	3.56						0.39		0.39
5/22/73	4.81	Snow	1.25					Snow	1.25		1	.40			3.56						.50		.50
7/20/73	2.65	Ice												2.65		Ice	-0.91	0.90	-0.82				- .82
10/25/7	1.70	Snow						Snow	.50		1	.30		1.20		Ice	-2.37	.90	-2.13		.15		-2.13
STAKE 73-19.0-D (installed 7/21/73)																							
7/21/73	4.85	Ice												4.85					- .82				- .82
10/25/7	3.98	Snow				0.55	5	Snow	.55	.03	5	.30		3.43	3.44	Ice	-1.41	.90	-2.09		.16		-2.09
3/28/74	4.35	Snow		0.29	0.90			Snow	.90		1	.29		3.45	3.44						.26		
STAKE 73-20 (installed 7/21/73)																							
7/21/73	3.85	Ice												3.85					- .82				
10/25/7	2.90	Snow				46	4	Snow	.46	.02	4	.30		2.44		Ice	-1.41	.90	-2.09		.14		-2.09
RESULTS FOR 1973 BALANCE YEAR: (for stake 73-20, the stake closest to the index site)																			-2.09				-2.09
DATA FOR 1974 BALANCE YEAR:																							
STAKE 73-19.0-D (continued)																							
3/28/74	4.35	Snow		0.29	0.90			Snow	0.90		1	0.29		3.45	3.44						0.26		0.26
7/21/74	2.10	Ice												2.10		Ice	-1.34	0.90	-1.21				-1.21
STAKE 73-20 (continued)																							
10/25/7	2.90	Snow				.46	4	Snow	.46	.02	4	.30		2.44							.14		
3/28/74	3.23	Snow	.79	.29				Snow	.79		1	.29			2.44						.23		.23
STAKE 74-20 (installed 3/28/74)																							
3/28/74	5.88	Snow	.79	29				Snow	79		1	.29		5.09							.23		23
7/21/74	3.28	Ice												3.28		Ice	-1.81	.90	-1.63				-1.63
3/2/75	2.50	Snow				1.45	10	Snow	1.45	.03	10	.32		1.06		Ice	-4.04	.90	-3.63		.46		
RESULTS FOR 1974 BALANCE YEAR: (for stake 74-20: the stake closest to the index site)																			-3.63				-3.63
DATA FOR 1975 BALANCE YEAR.																							
STAKE 75-20 (installed 3/2/75)																							
3/2/75	9.90	Snow				1.45	10	Snow	1.45	.03	10	.32		8.46							.46		.46
8/25/75	6.05	Ice												6.05		Ice	-2.41	0.90	-2.16				-2.16
3/24/76	7.07	Snow				1.28	8	Snow	1.28	.03	8	.32		5.79		Ice	-2.66	90	-2.40		.41		-2.40
RESULTS FOR 1975 BALANCE YEAR.																			-2.40				-2.40

Table 2E, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mea	n		Mean	s.e.	n	Est.	Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
									DATA FOR 1976 BALANCE YEAR:													
STAKE 75-20 (continued)																						
3/24/76	7.07	Snow				1.28	8	Snow	1.28	0.03	8	0.32	5.79							0.41		0.41
9/13/76	2.78	Snow			0.25			Snow	.25		1	.20	2.53		Ice	-3.26	0.90	-2.94		.05		-2.94
3/16/77	4.73	Snow				2.32	6	Snow	2.32	.01	6	.32	2.42	2.45	Ice	-3.35	.90	-3.01		.74		
3/19/77	4.70	Snow				2.23	4	Snow	2.23	.03	4	.32	2.48	2.45						.71		
Note. Temperature record from Gulkana Glacier indicates that melting after 9/13/76 is likely.																						
RESULTS FOR 1976 BALANCE YEAR:																		-3.01				-3.01
									DATA FOR 1977 BALANCE YEAR:													
STAKE 75-20 (continued)																						
3/16/77	4.73	Snow				2.32	6	Snow	2.32	.01	6	.32	2.42							.74		.74
3/19/77	4.70	Snow				2.23	4	Snow	2.23	.03	4	.32	2.48	2.45						.71		.71
STAKE 77-20 (installed 3/18/77)																						
3/16/77	9.00	Snow				2.33	5	Snow	2.33	.03	5	.32	6.67	6.71						.74		.74
3/19/77	8.98	Snow				2.23	4	Snow	2.23	.03	4	.32	6.76	6.71						.71		.71
9/21/77	4.55	Snow				.16	1	Snow	.16		1	.20	4.39		Ice	-2.32	.90	-2.09		.03		-2.09
RESULTS FOR 1977 BALANCE YEAR:																		-2.09				-2.09
									DATA FOR 1978 BALANCE YEAR:													
STAKE 77-20 (continued)																						
9/21/77	4.55	Snow				0.16	1	Snow	0.16		1	0.20	4.39							0.03		
3/18/78	5.95	Snow	1.56					Snow	1.56		1	.32		4.39						.50		0.50
9/23/78	1.04	Snow				.15	10	Snow	.15	.00	10	.20	.89	.87	Ice	-3.52	0.90	-3.17		.03		-3.17
3/29/79	2.28	Snow				1.43	10	Snow	1.43	.03	10	.32	.85	.87						.46		
RESULTS FOR 1978 BALANCE YEAR:																		-3.17				-3.17
									DATA FOR 1979 BALANCE YEAR:													
STAKE 77-20 (continued)																						
3/29/79	2.28	Snow				1.43	10	Snow	1.43	0.03	10	0.32	0.85	0.87						0.46		0.46
RESULTS FOR 1979 BALANCE YEAR:																						no results
									DATA FOR 1980 BALANCE YEAR:													
STAKE 80-20 (installed 3/26/80)																						
3/26/80	9.23	Snow				2.27	10	Snow	2.27	0.02	10	0.32	6.96							0.73		0.73
9/4/80	4.88	Snow				.07	15	Snow	.07	.01	15	.20	4.61		Ice	-2.15	0.90	-1.93		.01		-1.93
3/23/81	6.31	Snow				1.55	10	Snow	1.55	.03	10	.32	4.76		Ice	-2.20	.90	-1.98		.50		
Note: Temperature record from Gulkana Glacier indicates that melting after 9/4/80 is likely.																						
RESULTS FOR 1980 BALANCE YEAR:																		-1.98				-1.98
									DATA FOR 1981 BALANCE YEAR:													
STAKE 80-20 (continued)																						
3/23/81	6.31	Snow				1.55		Snow	1.55	0.03	10	0.32	4.76							0.50		0.50
6/22/81	4.65	Sup. ice			0.03			Sup. ic	.03		1	.90	4.62		Ice	-0.14	0.90	-0.13		.03		-.10
9/10/81	2.37	Snow				.01		Snow	.01		1	.20	2.36		Ice	-2.40	.90	-2.16		.00		-2.16
STAKE 81-20 (installed 3/23/81)																						
3/23/81	8.22	Snow				1.55		Snow	1.55	.03	10	.32	6.67	6.65						.50		.50
6/22/81	6.68	Sup. ice			.03			Sup. ic	.03		1	.90	6.63	6.65						.03		.03
9/10/81	4.31	Snow				.01		Snow	.01		1	.20	4.30		Ice	-2.35	.90	-2.11		.00		-2.11
3/25/82	5.59	Snow				1.40		Snow	1.40	.02	10	.32	4.20		Ice	-2.45	.90	-2.21		.45		-2.21
Note: Temperature record from Gulkana Glacier indicates that melting after 9/10/81 is likely. The net balance result for the year is the average b(i) on 9/10/81 plus the b(i) of stake 81-20 from 9/10/81 to the end of the balance year.																						
RESULTS FOR 1981 BALANCE YEAR: (average of stakes 80-20 and 81-20)																		-2.23				-2.23

Table 2E, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ		b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mea	n		Mean	s.e.	n	Est.		Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
														DATA FOR 1982 BALANCE YEAR:									
STAKE 81-20 (continued)																							
3/25/82	5.59	Snow				1.40	10	Snow	1.40	0.02	10	0.32		4.20							0.45		0.45
9/10/82	1.28	Ice												1.28		Ice	-2.92	0.90	-2.62				-2.62
4/21/83	2.90	Snow				1.77	10	Snow	1.77	.02	10	.32		1.13		Ice	-3.06	.90	-2.76		.57		-2.76
STAKE 82-20 (installed 3/25/82)																							
3/25/82	9.47	Snow				1.40	10	Snow	1.40	.02	10	.32		8.08							.45		.45
9/10/82	5.20	Ice												5.20		Ice	-2.88	.90	-2.59				-2.59
4/21/83	6.81	Snow				1.77	10	Snow	1.77	.02	10	.32		5.04		Ice	-3.03	.90	-2.73		.57		-2.73
RESULTS FOR 1982 BALANCE YEAR: (average of stakes 81-20 and 82-20)														5.04					-2.74				-2.74
														DATA FOR 1983 BALANCE YEAR:									
STAKE 82-20 (continued)																							
4/21/83	6.81	Snow				1.77	10	Snow	1.77	0.02	10	0.32		5.04							0.57		0.57
9/8/83	2.57	Snow				.14	12	Snow	.14	.01	12	.20		2.43	2.43	Ice	-2.61	0.90	-2.35		.03		-2.35
3/19/84	4.00	Snow				1.57	10	Snow	1.57	.04	10	.32		2.43	2.43						.50		
STAKE 83-20 (installed 4/21/83)																							
4/21/83	9.88	Snow				1.77	10	Snow	1.77	.02	10	.32		8.11							.57		.57
9/8/83	5.58	Snow				.14	12	Snow	.14	.01	12	.20		5.44	5.48	Ice	-2.63	.90	-2.37		.03		-2.37
3/19/84	7.09	Snow				1.57	10	Snow	1.57	.04	10	.32		5.52	5.48						.50		
RESULTS FOR 1983 BALANCE YEAR: (average of stakes 82-20 and 83-20)																			-2.36				-2.36
														DATA FOR 1984 BALANCE YEAR:									
STAKE 84-20 (installed 3/19/84)																							
3/19/84	11.42	Snow				1.57	10	Snow	1.57	0.04	10	0.32		9.85							0.50		0.50
8/26/84	7.27	Ice												7.27		Ice	-2.58	0.90	-2.32				-2.32
4/4/85	8.93	Snow				1.67	10	Snow	1.67	.03	10	.32		7.27							.53		
RESULTS FOR 1984 BALANCE YEAR:																			-2.32				-2.32
														DATA FOR 1985 BALANCE YEAR:									
STAKE 84-20 (continued)																							
4/4/85	8.93	Snow				1.67		Snow	1.67	0.03	10	0.32		7.27							0.53		0.53
9/11/85	5.17	Snow			0.03			Snow	.03		1	.20		5.14		Ice	-2.13	0.90	-1.91		.01		-1.91
4/2/86	6.60	Snow				1.72		Snow	1.72	.03	8	.32		4.89		Ice	-2.38	.90	-2.14		.55		-2.14
RESULTS FOR 1985 BALANCE YEAR:																			-2.14				-2.14
														DATA FOR 1986 BALANCE YEAR:									
STAKE 84-20 (continued)																							
4/2/86	6.60	Snow				1.72	8	Snow	1.72	0.03	8	0.32		4.88							0.55		0.55
9/25/86	2.32	Snow				.27	10	Snow	.27	.02	10	.30		2.06		Ice	-2.83	0.90	-2.54		.08		-2.54
STAKE 86-20 (installed 4/2/86)																							
4/2/86	10.76	Snow				1.72	8	Snow	1.72	.03	8	.32		9.05					.00		.55		.55
9/25/86	6.23	Snow				.27	10	Snow	.27	.02	10	.20		5.97	5.99	Ice	-3.06	.90	-2.75		.05		-2.75
3/18/87	7.92	Snow				1.92	10	Snow	1.92	.03	10	.32		6.01	5.99						.61		
RESULTS FOR 1986 BALANCE YEAR: (average of stakes 84-20 and 86-20)																			-2.65				-2.65

Table 2E, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mea	n		Mean	s.e.	n	Est.	Obsv.	Est			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1987 BALANCE YEAR:																							
STAKE 86-20 (continued)																							
3/18/87	7.92	Snow				1.92	10	Snow	1.92	0.03	10	0.32	6.01	5.99						0.61		0.61
8/27/87	3.57	Ice											3.57		Ice	-2.42	0.90	-2.17				
STAKE 87-20 (installed 3/18/87)																							
3/18/87	8.97	Snow				1.92	10	Snow	1.92	.03	10	.32	7.06							.61		.61
8/27/87	4.66	Ice											4.66		Ice	-2.40	.90	-2.16				-2.16
4/16/88	6.35	Snow				2.37	4	Snow	2.37	.08	4	.32	3.98		Ice	-3.08	.90	-2.77		.76		-2.77
RESULTS FOR 1987 BALANCE YEAR																		-2.77				-2.77
DATA FOR 1988 BALANCE YEAR:																							
STAKE 87-20 (continued)																							
4/16/88	6.35	Snow				2.37	4	Snow	2.37	0.08	4	.32	3.98							0.76		0.76
4/15/89	3.11	Snow				1.50	1	Snow	1.50		1	.32	1.61		Ice	-2.37	0.90	-2.13		.48		-2.13
RESULTS FOR 1988 BALANCE YEAR																		-2.13				-2.13
DATA FOR 1989 BALANCE YEAR:																							
STAKE 87-20 (continued)																							
4/15/89	3.11	Snow				1.50		Snow	1.50		1	0.32	1.61							0.48		
RESULTS FOR 1989 BALANCE YEAR:																							no results
DATA FOR 1990 BALANCE YEAR.																							
STAKE 90-20 (installed 5/26/90)																							
5/26/90	11.82	Snow				1.80	1	Snow	1.80		1	0.32	10.02							0.58		0.58
5/1/91	7.91	Snow				1.50	10	Snow	1.50	.03	10	.32	6.41		Ice	-3.62	0.90	-3.25		.48		-3.25
RESULTS FOR 1990 BALANCE YEAR																		-3.25				-3.25
DATA FOR 1991 BALANCE YEAR.																							
STAKE 90-20 (continued)																							
5/1/91	7.91	Snow				1.50	10	Snow	1.50	0.03	10	0.32	6.41							0.48		0.48
5/2/92	5.55	Snow				2.06	10	Snow	2.06	.06	10	.32	3.49		Ice	-2.92	0.90	-2.62		.66		-2.62
RESULTS FOR 1991 BALANCE YEAR:																		-2.62				-2.62
DATA FOR 1992 BALANCE YEAR:																							
STAKE 90-20 (continued)																							
5/2/92	5.55	Snow				2.06	10	Snow	2.06	0.06	10	0.32	3.49							0.66		0.66
9/23/92	1.37	Snow			.26	.37	20	Snow	.37	.02	21	.20	1.00		Ice	-2.49	0.90	-2.24		.07		-2.24
STAKE 92-20 (installed 5/2/92)																							
5/2/92	11.42	Snow				2.06	10	Snow	2.06	.06	10	.32	9.36							.66		.66
9/23/92	7.25	Snow			.26	.37	20	Snow	.37	.02	21	.20	6.88		Ice	-2.48	.90	-2.24		.07		-2.24
RESULTS FOR 1992 BALANCE YEAR:																		-2.24				-2.24

Table 2F. Mass balance, 26 km site, Black Rapids Glacier

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter, d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error, Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake, Obsv., observed; b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation–rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations							Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stak	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1972 BALANCE YEAR:																						
STAKE 73-4 (range motion site C, 25.2 km, installed 8/3/72)																						
8/3/72	5.44	Ice											5.44									
10/19/7	4.28	Snow				0.53	8	Snow	0.53	0.08	8	0.20	3.75	3.83						0.11		
4/1/73	4.92	Snow				1.02	8	Snow	1.02	.08	8	.31	3.90	3.83						.32		
RESULTS FOR 1972 BALANCE YEAR:																						no results
DATA FOR 1973 BALANCE YEAR:																						
STAKE 73-4 (continued)																						
4/1/73	4.92	Snow				1.02	8	Snow	1.02	0.08	8	0.31	3.90	3.83						0.32		0.32
5/22/73	4.77	Snow	0.94					Snow	.94		1	.40		3.83						32		.32
7/24/73	1.60	Ice											1.60		Ice	-2.23	0.90	-2.00				
STAKE 73-26.0 (installed 7/21/73)																						
7/21/73	5.00	Ice											5.00					-2.00				-2.00
10/25/7	3.22	Snow				.48	4	Snow	.48		4	20	2.75	2.70	Ice		.90	-4.08		.10		-4.08
3/29/74	3.70	Snow				1.05	1	Snow	1.05		1	.31	2.65	2.70						.33		
RESULTS FOR 1973 BALANCE YEAR:																		-4.08				-4.08
DATA FOR 1974 BALANCE YEAR:																						
STAKE 74-26.0 (installed 3/29/74)																						
3/29/74	6.34	Snow				1.05		Snow	1.05		1	0.31	5.29							0.33		0.33
7/21/74	3.50	Ice											3.50		Ice	-1.79	0.90	-1.61				-1.61
3/3/75	2.12	Snow	0.31	1.21		1.62	13	Snow	1.59	0.09	14	obsv.	.53		Ice	-4.76	.90	-4.28		.49		
RESULTS FOR 1974 BALANCE YEAR:																		-4.28				-4.28
DATA FOR 1975 BALANCE YEAR:																						
STAKE 75-26.0 (installed 3/3/75)																						
3/3/75	9.90	Snow	0.31	1.21		1.62	13	Snow	1.59	.09	14	obsv.	8.31							0.49		0.49
8/26/75	5.00	Ice											5.00		Ice	-3.31	0.90	-2.98				-2.98
3/26/76	6.66	Snow				1.81		Snow	1.81	.09	12	0.31	4.85		Ice	-3.46	.90	-3.12		.56		
RESULTS FOR 1975 BALANCE YEAR:																		-3.12				-3.12
DATA FOR 1976 BALANCE YEAR:																						
STAKE 75-26 (continued)																						
3/26/76	6.66	Snow				1.81		Snow	1.81	0.09	12	0.31	4.85							0.56		0.56
9/13/76	1.27	Ice											1.27	1.30	Ice	-3.55	0.90	-3.20				-3.20
3/16/77	3.50	Snow				2.17		Snow	2.17	.01	6	.31	1.33	1.30						.67		
RESULTS FOR 1976 BALANCE YEAR:																		-3.20				-3.20
DATA FOR 1977 BALANCE YEAR:																						
STAKE 77-26 (installed 3/16/77)																						
3/16/77	9.05	Snow				2.17		Snow	2.17	0.01	6	0.31	6.88							0.67		0.67
9/20/77	3.57	Snow				.02		Snow	.02		1	.20	3.55		Ice	-3.33	0.90	-3.00		.00		-3.00
RESULTS FOR 1977 BALANCE YEAR:																		-3.00				-3.00

Table 2F, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations				Mass balance results				
Date	Stake reading		Stak	Pit		Probe d(s)		Material	Thickness			ρ	b's		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e	n	Est	Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
									DATA FOR 1978 BALANCE YEAR:														
STAKE 77-26 (continued)																							
3/19/78	5.26	Snow	1.71					Snow	1.71		1	0.31		3.55						0.53		0.53
STAKE 78-26 (installed 3/19/78)																							
3/19/78	9.02	Snow	1.71					Snow	1.71		1	.31	7.31							.53		.53
9/23/78	3.50	Snow				0.12	10	Snow	.12	0.01	10	.20	3.38		Ice	-3.93	0.90	-3.54		.02		-3.54
3/29/79	4.62	Snow				1.43	10	Snow	1.43	.05	10	.31	3.19		Ice	-4.12	.90	-3.71		.44		-3.71
RESULTS FOR 1978 BALANCE YEAR:																		-3.71				-3.71
									DATA FOR 1979 BALANCE YEAR:														
STAKE 79-26 (installed 3/29/79)																							
3/29/79	8.85	Snow				1.43	10	Snow	1.43	0.05	10	0.31	7.42							0.44		0.44
8/23/79	3.04	Ice											3.04		Ice	-4.38	0.90	-3.94				-3.94
3/26/80	4.63	Snow				1.87	10	Snow	1.87	.03	10	.31	2.76		Ice	-4.66	.90	-4.20		.58		-4.20
RESULTS FOR 1979 BALANCE YEAR:																		-4.20				-4.20
									DATA FOR 1980 BALANCE YEAR:														
STAKE 80-26 (installed 3/26/80)																							
3/26/80	8.73	Snow				1.87	10	Snow	1.87	0.03	10	0.31	6.86							0.58		0.58
9/4/80	3.62	Ice											3.62		Ice	-3.24	0.90	-2.91				-2.91
3/24/81	4.48	Snow				1.13	10	Snow	1.13	.03	10	.31	3.35		Ice	-3.51	.90	-3.16		.35		
RESULTS FOR 1980 BALANCE YEAR:																		-3.16				-3.16
									DATA FOR 1981 BALANCE YEAR:														
STAKE 79-26 (continued)																							
3/24/81	4.48	Snow				1.13	10	Snow	1.13	0.03	10	0.31	3.35							0.35		0.35
6/22/81	2.50	Ice											2.50		Ice	-0.85	0.90	-0.77				-.77
STAKE 81-26 (installed 3/24/81)																							
3/24/81	8.22	Snow				1.13	10	Snow	1.13	.03	10	.31	7.09							.35		.35
6/22/81	6.50	Ice											6.50		Ice	-.59	.90	-0.53				-.53
9/22/81	2.85	Snow				.07	7	Snow	.07	.01	7	.20	2.78	2.63	Ice	-4.46	.90	-4.01		.01		-4.01
3/22/82	3.83	Snow				1.35	21	Snow	1.35	.05	21	.31	2.48	2.63						.42		
Note: Temperature record from Gulkana Glacier indicates that melting after 9/22/81 is unlikely. The net balance result for the year is the average b(i) on 9/22/81 plus the b(i) of stake 81-26 from 9/22/81 to the end of the balance year.																							
RESULTS FOR 1981 BALANCE YEAR:																		-4.13				-4.13
									DATA FOR 1982 BALANCE YEAR:														
STAKE 82-26 (installed 3/22/82)																							
3/22/82	9.50	Snow				1.35	21	Snow	1.35	0.05	21	0.31	8.15							0.42		0.42
9/10/82	4.08	Ice											4.08		Ice	-4.07	0.90	-3.66				-3.66
4/20/83	5.35	Snow				1.80	20	Snow	1.80	.06	20	.31	3.55		Ice	-4.60	.90	-4.14		.56		-4.14
RESULTS FOR 1982 BALANCE YEAR:																		-4.14				-4.14
									DATA FOR 1983 BALANCE YEAR:														
STAKE 83-26 (installed 4/20/83)																							
4/20/83	8.90	Snow				1.80	20	Snow	1.80	.06	20	.31	7.10							.56		.56
9/8/83	3.98	Snow				.09	8	Snow	.09	.03	8	.20	3.89		Ice	-3.21	0.90	-2.89		.02		-2.89
3/19/84	4.95	Snow				1.41	17	Snow	1.41	.04	17	.31	3.54		Ice	-3.56	.90	-3.20		.44		-3.20
RESULTS FOR 1983 BALANCE YEAR:																		-3.20				-3.20

Table 2F, continued

Observations							Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1984 BALANCE YEAR:																						
STAKE 84-26 (installed 3/19/84)																						
3/19/84	11.87	Snow				1.41	17	Snow	1.41	0.04	17	0.31	10.46							0.44		0.44
8/28/84	8.45	Ice											6.45		Ice	-4.01	0.90	-3.61				-3.61
4/5/85	7.61	Snow				1.34	29	Snow	1.34	.03	29	.31	6.27		Ice	-4.20	.90	-3.78		.42		-3.78
RESULTS FOR 1984 BALANCE YEAR																		-3.78				-3.78
DATA FOR 1985 BALANCE YEAR:																						
STAKE 84-26 (continued)																						
4/5/85	7.61	Snow				1.34	29	Snow	1.34	0.03	29	0.31	6.27							0.42		0.42
9/5/85	2.77	Snow				.03	1	Snow	.03		1	.20	2.74	2.80	Ice	-3.46	0.90	-3.12		.01		-3.12
4/9/86	3.95	Snow				1.08	15	Snow	1.08	.04	15	.31	2.87	2.80						.34		
STAKE 85-26 (installed 4/5/85)																						
4/5/85	12.93	Snow				1.34	29	Snow	1.34	.03	29	.31	11.59							.42		.42
9/5/85	8.35	Snow				.03	1	Snow	.03		1	.20	8.32	8.21	Ice	-3.37	.90	-3.04		.01		-3.04
4/9/86	9.19	Snow				1.08	15	Snow	1.08	.04	15	.31	8.11	8.21						.34		
RESULTS FOR 1985 BALANCE YEAR: (average of stakes 84-26 and 85-26)																		-3.08				-3.08
DATA FOR 1986 BALANCE YEAR:																						
STAKE 85-26 (continued)																						
4/9/86	9.19	Snow				1.08	15	Snow	1.08	0.04	15	0.31	8.11	8.21						0.34		0.34
10/7/86	3.64	Snow				.24	13	Snow	.24	.02	13	.20	3.40		Ice	-4.82	0.90	-4.34		.05		-4.34
3/19/87	4.94	Snow				1.54	17	Snow	1.54	.04	17	.31	3.40							.48		
RESULTS FOR 1986 BALANCE YEAR																		-4.34				-4.34
DATA FOR 1987 BALANCE YEAR.																						
STAKE 87-26 (installed 3/19/87)																						
3/19/87	9.00	Snow				1.54	17	Snow	1.54	0.04	17	0.31	7.46							0.48		0.48
4/22/88	5.56	Snow				2.09	1	Snow	2.09		1	.31	3.47		Ice	-3.99	0.90	-3.59		.65		
STAKE 87-26I (installed 3/19/87)																						
3/19/87	9.73	Snow				1.54	17	Snow	1.54	.04	17	.31	8.19							.48		
8/27/87	3.83	Ice											3.83		Ice	-4.36	.90	-3.93				-3.93
4/22/88	4.92	Snow				1.71	1	Snow	1.71		1	.31	3.21		Ice	-4.98	.90	-4.49		.53		
RESULTS FOR 1987 BALANCE YEAR: (stake 87-26I best data)																		-4.49				-4.49
DATA FOR 1988 BALANCE YEAR:																						
STAKE UA88-26 (installed 4/22/88)																						
4/22/88	9.69	Snow				1.58	2	Snow	1.58	0.04	2	0.31	8.11							0.49		0.49
9/2/88	3.63	Snow				.02	1	Snow	.02		1	.20	3.61		Ice	-4.50	0.90	-4.05		.00		-4.05
4/21/89	4.37	Snow				1.07	1	Snow	1.07		1	.31	3.31		Ice	-4.81	.90	-4.33		.33		
RESULTS FOR 1988 BALANCE YEAR:																		-4.33				-4.33
DATA FOR 1989 BALANCE YEAR.																						
STAKE UA89-26 (installed 4/21/89)																						
4/21/89	8.40	Snow				1.07	1	Snow	1.07		1	0.31	7.33							0.33		0.33
5/26/90	3.65	Snow				.78	1	Snow	.78		1	.40	2.87		Ice	-4.47	0.90	-4.02		.31		-4.02
RESULTS FOR 1989 BALANCE YEAR.																		-4.02				-4.02

Table 2G. Mass balance, 32 km site, Black Rapids Glacier

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter; d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error; Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed; b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation–rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations						Summer surface b'ss		Ablation calculations			Mass balance results				
Date	Stake reading b'	Surface material	Stake d(s)	Pit ρ	Pit d(s)	Probe d(s) Mean	Probe d(s) n	Material	Thickness Mean	Thickness s.e.	Thickness n	ρ Est.	Obsv.	Est.	Material	Change	ρ Est.	Ice b(i)	Firn b(f)	Snow b(s)	Internal b(k)	Net b_n
m/d/y	(m)		(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1972 BALANCE YEAR:																						
STAKE 72-2 (installed 4/24/72)																						
4/24/72	7.82	Snow				1.32	10	Snow	1.32	0.07	10	0.35	6.50							0.46		0.46
8/3/72	3.50	Ice											3.50		Ice	-3.00	0.90	-2.70				
STAKE 73-3 (installed 8/3/72)																						
8/3/72	5.85	Ice											5.85					-2.70				-2.70
8/5/72	5.60	Ice											5.60		Ice	-3.25	.90	-2.93				-2.93
10/18/7	4.32	Snow				.14	6	Snow	.14	.04	6	.20	4.19	4.13	Ice	-4.72	.90	-4.25		.03		-4.25
4/4/73	4.74	Snow		0.33	0.83	.65	8	Snow	.67	.04	9	.33	4.07	4.13						.22		
RESULTS FOR 1972 BALANCE YEAR:																		-4.25				-4.25
DATA FOR 1973 BALANCE YEAR:																						
STAKE 73-3 (continued)																						
4/4/73	4.74	Snow		0.33	0.83	0.65	8	Snow	0.67	0.04	9	0.33	4.07	4.13						0.22		0.22
7/22/73	1.25	Ice											1.25		Ice	-2.88	0.90	-2.59				
STAKE 73-32-B (installed 7/22/73)																						
7/22/73	5.00	Ice											5.00					-2.59				
10/25/7	3.24	Snow				.47	9	Snow	.47	.03	9	.20	2.77	2.71	Ice	-2.29	.90	-4.65		.09		-4.65
3/29/74	3.33	Snow				.68	6	Snow	.68	.04	6	.35	2.65							.24		
RESULTS FOR 1973 BALANCE YEAR:																		-4.65				-4.65
DATA FOR 1974 BALANCE YEAR:																						
STAKE 74-32-B (installed 3/29/74)																						
3/29/74	6.38	Snow				0.68	6	Snow	0.68	0.04	6	0.35	5.70							0.24		0.24
7/21/74	2.60	Ice											2.60		Ice	-3.10	0.90	-2.79				-2.79
RESULTS FOR 1974 BALANCE YEAR:																						no results
DATA FOR 1975 BALANCE YEAR:																						
STAKE 75-32.5-B (installed 3/4/75)																						
3/4/75	10.06	Snow				1.20	10	Snow	1.20	.03	10	0.35	8.86							0.42		0.42
8/25/75	4.71	Ice											4.71		Ice	-4.15	0.90	-3.73				-3.73
3/26/76	5.38	Snow		0.27	1.14	1.44	10	Snow	1.42	.06	11	.27	3.94		Ice	-4.91	.90	-4.42		.38		
RESULTS FOR 1975 BALANCE YEAR:																		-4.42				-4.42
DATA FOR 1976 BALANCE YEAR:																						
STAKE 76-32 (installed 3/26/76)																						
3/26/76	10.07	Snow		0.27	1.14	1.44	10	Snow	1.42	0.06	11	0.27	8.65							0.38		0.38
9/13/76	3.27	Ice											3.27	3.34	Ice	-5.32	.90	-4.79				-4.79
3/14/77	5.45	Snow			1.58	2.10	7	Snow	2.05	.03	7	.35	3.40	3.34						.72		
RESULTS FOR 1976 BALANCE YEAR:																		-4.79				-4.79

Table 2G, continued

Observations							Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(ir)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1977 BALANCE YEAR																						
STAKE 77-32 (installed 3/14/77)																						
3/14/77	8.48	Snow		0.36	1.68	2.10	7	Snow	2.05	0.03	8	0.35	6.43							0.72		.72
9/20/77	1.49	Ice											1.49		Ice	-4.94	.90	-4.45				-4.45
Temperature record from Gulkana Glacier indicates that melting after 9/20/77 is unlikely																						
RESULTS FOR 1977 BALANCE YEAR:																		-4.45				-4.45
DATA FOR 1978 BALANCE YEAR:																						
Stake 77-32 (continued)																						
3/23/78	2.95	Snow	1.46					Snow	1.46		1	0.35		1.49						0.51		0.51
STAKE 78-32 (installed 3/23/78)																						
3/23/78	8.85	Snow	1.46					Snow	1.46		1	.35	7.39							.51		.51
9/22/78	1.82	Snow				0.13		Snow	.13	0.01	10	.20	1.69		Ice	-5.70	.90	-5.13		.03		-5.13
3/29/79	3.16	Snow				1.22	10	Snow	1.22	0.03	10	.35	1.93							0.43		0.43
Note: This stake probably sank.																						
RESULTS FOR 1978 BALANCE YEAR:																		-5.13				-5.13
DATA FOR 1979 BALANCE YEAR.																						
RESULTS FOR 1979 BALANCE YEAR:																						no results
DATA FOR 1980 BALANCE YEAR																						
STAKE 80-32 (installed 3/29/80)																						
3/29/80	10.04	Snow				1.94	10	Snow	1.94	0.03	10	0.35	8.10							0.68		0.68
9/4/80	3.69	Ice											3.69	3.70	Ice	-4.41	.90	-3.97				-3.97
3/24/81	4.97	Snow				1.27	10	Snow	1.27	.04	10	.35	3.70	3.70						.44		
RESULTS FOR 1980 BALANCE YEAR:																		-3.97				-3.97
DATA FOR 1981 BALANCE YEAR:																						
STAKE 81-32 (installed 3/24/81)																						
3/24/81	8.86	Snow				1.27	10	Snow	1.27	0.04	10	0.35	7.59							0.44		0.44
9/14/81	2.31	Ice											2.31		Ice	-5.28	0.90	-4.75				-4.75
3/22/82	3.48	Snow				1.01	20	Snow	1.01	.03	20	.35	2.47							.35		
Note. Stake apparently sank. Gulkana Glacier temperature records show six days of mean temperatures above 0 C after 9/14/81. Estimate 15 cm of additional ablation after 9/14/81																						
RESULTS FOR 1981 BALANCE YEAR:																		-4.90				-4.90
DATA FOR 1982 BALANCE YEAR:																						
STAKE 82-32 (installed 3/22/82)																						
3/22/82	9.68	Snow				1.01	20	Snow	1.01	0.03	20	0.35	8.67							0.35		0.35
9/11/82	3.60	Ice											3.60		Ice	-5.07	0.90	-4.56				-4.56
4/20/83	4.73	Snow		0.32	1.57	1.63	10	Snow	1.63	.02	11	.32	3.10		Ice	-5.57	.90	-5.01		.52		-5.01
RESULTS FOR 1982 BALANCE YEAR:																		-5.01				-5.01
DATA FOR 1983 BALANCE YEAR:																						
STAKE 83-32 (installed 4/20/83)																						
4/20/83	9.52	Snow		0.32	1.57	1.63	10	Snow	1.63	.02	11	0.32	7.89							0.52		0.52
9/8/83	3.52	Ice											3.52		Ice	-4.37	0.90	-3.94				-3.94
3/18/84	4.73	Snow		.36	1.39	1.34	14	Snow	1.34	.02	15	.36	3.39		Ice	-4.50	.90	-4.05		.48		-4.05
RESULTS FOR 1983 BALANCE YEAR:																		-4.05				-4.05

Table 2G, continued

Observations								Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)
DATA FOR 1984 BALANCE YEAR:																						
STAKE 84-32 (installed 3/18/84)																						
3/18/84	14.50	Snow		0.36	1.39	1.34	14	Snow	1.34	0.02	15	0.36	13.18							0.48		0.48
8/28/84	8.41	Ice											8.41		Ice	-4.75	0.90	-4.27				-4.27
4/5/85	9.66	Snow				1.34		Snow	1.34	.05	12	.35	8.32		Ice	-4.84	.90	-4.36		.47		-4.36
RESULTS FOR 1984 BALANCE YEAR:																		-4.36				-4.36
DATA FOR 1985 BALANCE YEAR:																						
STAKE 84-32 (continued)																						
4/5/85	9.66	Snow				1.34		Snow	1.34	0.06	12	0.35	8.32							0.47		0.47
9/5/85	4.36	Ice											4.36		Ice	-3.96	0.90	-3.56				-3.56
STAKE 85-32 (installed 4/5/85)																						
4/5/85	10.50	Snow				1.34		Snow	1.34	.05	12	.35	9.16							.47		.47
9/5/85	4.90	Ice											4.90		Ice	-4.26	.90	-3.83				-3.83
4/9/86	6.28	Snow				1.66		Snow	1.66	.04	15	.35	4.62		Ice	-4.54	.90	-4.09		58		-4.09
Note: The net balance result for the year is the average b(i) on 9/5/85 plus the b(i) of stake 85-32 from 9/5/85 to the end of the balance year.																						
RESULTS FOR 1985 BALANCE YEAR: (average of stakes 84-32 and 85-32)																		-3.95				-3.95
DATA FOR 1986 BALANCE YEAR																						
STAKE 86-32 (installed 4/9/86)																						
4/9/86	8.86	Snow				1.66	15	Snow	1.66	0.04	15	0.35	7.20							0.58		58
10/7/86	2.52	Ice											2.52	2.28	Ice	-4.92	0.90	-4.42				-4.42
3/19/87	3.68	Snow				1.62	10	Snow	1.62	.07	10	35	2.04	2.28						.57		
Note: Stake was severely affected by ice melt around base, giving mediocre results.																						
RESULTS FOR 1986 BALANCE YEAR:																		-4.42				-4.42
DATA FOR 1987 BALANCE YEAR:																						
STAKE 87-32 (installed 3/19/87)																						
3/19/87	9.94	Snow				1.62	10	Snow	1.62	0.07	10	0.35	8.32							0.57		0.57
8/27/87	4.10	Ice											4.10		Ice	-4.22	0.90	-3.80				-3.80
4/19/88	5.99	Snow			2.38			Snow	2.38		1	.35	3.61		Ice	-4.72	.90	-4.24		.83		
RESULTS FOR 1987 BALANCE YEAR:																		-4.24				-4.24
DATA FOR 1988 BALANCE YEAR.																						
Note: Site move to 31 km																						
STAKE UA87-31 (installed 4/30/87)																						
3/14/88	6.36	Snow				1.70		Snow	1.70			0.35	3.67							0.59		0.59
4/19/88	6.00	Snow				2.38		Snow	2.38		1	.35	3.62							83		.83
STAKE UA88-31 (installed 4/19/88)																						
4/19/88	11.04	Snow				2.38		Snow	2.38		1	.35	8.66							83		.83
4/21/89	5.33	Snow				61		Snow	.61		1	35	4.72		Ice	-3.95	0.90	-3.55		21		-3.55
Note: Snow depth on 4/21/89 estimated from measurements at 26 km and 38 km sites																						
RESULTS FOR 1988 BALANCE YEAR:																		-3.55				-3.55

Table 2H. Mass balance, 38 km site, Black Rapids Glacier

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter; d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error; Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed; b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation--rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	hang	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1973 BALANCE YEAR:																						
STAKE 73-38.0 (installed 7/22/73)																						
7/22/73	5.20	Ice											5.20									
10/25/73	2.42	Snow				0.13	7	Snow	0.13	0.07	7	0.20	2.29							0.03		
RESULTS FOR 1973 BALANCE YEAR:																						no results
DATA FOR 1974 BALANCE YEAR.																						
STAKE 73-38.0 (continued)																						
3/31/74	2.34	Snow				0.51	6	Snow	0.51	0.06	6	0.36	1.83							0.18		0.18
STAKE 74-38.8 (installed 3/31/74)																						
3/31/74	9.00	Snow				.51	6	Snow	.51	.06	6	.36	8.49							.18		18
7/21/74	5.00	Ice											5.00		Ice	-3.49	0.90	-3.14				-3.14
RESULTS FOR 1974 BALANCE YEAR:																						no results
DATA FOR 1975 BALANCE YEAR:																						
STAKE 75-38.8 (installed 3/6/75)																						
3/6/75	10.00	Snow	0.36	1.26		0.92	15	Snow	0.92	0.10	16		9.08							0.33		0.33
8/25/75	4.50	Ice											4.50		Ice	-4.58	0.90	-4.12				-4.12
3/26/76	3.85	Snow				.80	1	Snow	.80		1	0.36	3.08		Ice	-6.02	.90	-5.42		.29		
RESULTS FOR 1975 BALANCE YEAR:																		-5.42				-5.42
DATA FOR 1976 BALANCE YEAR:																						
STAKE 76-38 (altitude 942 m, installed 3/26/76)																						
3/28/76	6.25	Snow				0.80		Snow	0.80		1	0.36	5.45							0.29		0.29
9/13/76	.00	Ice	completely ablated out																			
RESULTS FOR 1976 BALANCE YEAR:																						no results
DATA FOR 1977 BALANCE YEAR:																						
STAKE 77-38 (installed 3/14/77)																						
3/14/77	8.45	Snow				0.70	10	Snow	0.70	0.02	10	0.36	7.75							0.25		0.25
9/19/77	1.00	Ice											1.00	1.06	Ice	-6.69	0.90	-6.02				-6.02
3/20/78	2.31	Snow				1.19	10	Snow	1.19	.04	10	.36	1.12	1.06						43		
RESULTS FOR 1977 BALANCE YEAR:																		-6.02				-6.02
DATA FOR 1978 BALANCE YEAR:																						
STAKE 78-38.3 (installed 3/20/78)																						
3/20/78	10.19	Snow				1.19	10	Snow	1.19	0.04	10	0.36	9.00							0.43		0.43
9/23/78	2.12	Snow				.08	4	Snow	.08	.00	4	20	2.04	2.27	Ice	-6.74	0.90	-6.06		.02		-6.06
3/29/79	2.79	Snow				30	18	Snow	30	.04	18	.36	2.49	2.27						.11		
RESULTS FOR 1978 BALANCE YEAR:																		-6.06				-6.06
DATA FOR 1979 BALANCE YEAR.																						
STAKE 79-38.3 (installed 3/29/79)																						
3/29/79	8.85	Snow				0.30	18	Snow	0.30		18	0.36	8.55							0.11		0.11
8/23/79	2.23	Ice											2.23		Ice	-6.32	0.90	-5.69				-5.69
3/29/80	1.13	Snow				.21	10	Snow	.21	04	10	.36	92		Ice	-7.63	.90	-6.87		.08		
RESULTS FOR 1979 BALANCE YEAR:																		-6.87				-6.87

Table 2H, continued

Observations								Accumulation calculations						Summer surface b'ss		Ablation calculations			Mass balance results				
Date	Stake reading b'	Stake Surface material	Stake d(s)	Pit ρ	Pit d(s)	Probe d(s) Mean	Probe d(s) n	Material	Thickness Mean	Thickness s.e.	Thickness n	ρ Est.	b'ss Obsv.	b'ss Est.	Material	hang	ρ Est.	Ice b(i)	Firn b(f)	Snow b(s)	Internal b(k)	Net b_n
m/d/y	(m)		(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1980 BALANCE YEAR:																						
STAKE 80-38 (installed 3/29/80)																						
3/29/80	9.82	Snow				0.21	10	Snow	0.21	0.04	10	0.36	9.61							0.08		0.08
9/4/80	3.13	Ice											3.13		Ice	-6.48	0.90	-5.83				-5.83
3/24/81	2.84	Snow				.13	10	Snow	.13	.03	10	.36	2.71		Ice	-6.90	.90	-6.21		.05		
RESULTS FOR 1980 BALANCE YEAR:																		-6.21				-6.21
DATA FOR 1981 BALANCE YEAR:																						
STAKE 81-38.3 (installed 3/24/81)																						
3/24/81	9.44	Snow				0.13	10	Snow	0.13	0.03	10	0.36	9.31							0.05		0.05
9/14/81	2.11	Ice											2.11		Ice	-7.20	0.90	-6.48				-6.48
3/22/82	2.22	Snow				.12	10	Snow	.12	.03	10	.36	2.10		Ice	-7.21	.90	-6.49		.04		
RESULTS FOR 1981 BALANCE YEAR:																		-6.49				-6.49
DATA FOR 1982 BALANCE YEAR:																						
STAKE 82-38 (installed 3/22/82)																						
3/22/82	9.95	Snow				0.12	10	Snow	0.12	0.03	10	0.36	9.83							0.04		0.04
9/11/82	3.17	Ice											3.17		Ice	-6.66	0.90	-5.99				-5.99
4/20/83	3.36	Snow				.49	10	Snow	.49	.07	10	.36	2.87		Ice	-6.95	.90	-6.26		.18		
RESULTS FOR 1982 BALANCE YEAR:																		-6.26				-6.26
DATA FOR 1983 BALANCE YEAR:																						
STAKE 83-38 (installed 4/20/83)																						
4/20/83	9.95	Snow				0.49	10	Snow	.49	0.07	10	0.36	9.46							0.18		0.18
9/8/83	3.67	Ice											3.67		Ice	-5.79	0.90	-5.21				-5.21
3/18/84	3.46	Snow				24	15	Snow	24	.03	15	36	3.22		Ice	-8.24	.90	-5.62		.09		
RESULTS FOR 1983 BALANCE YEAR:																		-5.62				-5.62
DATA FOR 1984 BALANCE YEAR:																						
STAKE 84-38 (installed 3/18/84)																						
3/18/84	14.83	Snow				0.24	15	Snow	.24	0.03	15	0.36	14.59							0.09		0.09
8/29/84	8.46	Ice											8.46		Ice	-6.13	0.90	-5.52				-5.52
4/5/85	8.24	Snow				.28	15	Snow	.28	.03	15	.36	7.96		Ice	-6.63	90	-5.97		.10		
RESULTS FOR 1984 BALANCE YEAR:																		-5.97				-5.97
DATA FOR 1985 BALANCE YEAR:																						
STAKE 84-38 (continued)																						
4/5/85	8.24	Snow				0.28	15	Snow	0.28	0.03	15	0.36	7.96							0.10		0.10
9/5/85	2.51												2.51		Ice	-5.45	0.90	-4.91				-4.91
4/6/86	2.53	Snow				45	20	Snow	.45	.03	20	.36	2.08		Ice	-5.88	90	-5.29		.16		
STAKE 85-38 (installed 4/6/85)																						
4/6/85	11.14	Snow				.28	15	Snow	.28	.03	15	.36	10.86					.00		.10		.10
9/5/85	5.51												5.51		Ice	-5.35	90	-4.82				-4.82
4/6/86	5.43	Snow				.45	20	Snow	.45	.03	20	.36	4.98		Ice	-5.88	.90	-5.29		.16		
RESULTS FOR 1985 BALANCE YEAR:																		-5.29				-5.29
DATA FOR 1986 BALANCE YEAR:																						
STAKE 86-38 (installed 4/6/86)																						
4/6/86	10.05	Snow				0.45	20	Snow	0.45	0.03	20	0.36	9.60							0.16		0.16
10/7/86	2.85	Ice											2.85		Ice	-6.75	0.90	-6.08				-6.08
3/19/87	2.65	Snow				.03	1	Snow	.03		1	.36	2.62		Ice	-6.98	.90	-6.29		.01		
RESULTS FOR 1986 BALANCE YEAR:																		-6.29				-6.29

Table 2H, continued

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	hang	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv.	Est			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1987 BALANCE YEAR:																							
STAKE 87-38 (installed 3/19/87)																							
3/19/87	9.93	Snow				0.03	1	Snow	0.03		1	0.36	9.90							0.01		0.01
8/27/87	4.00	Ice											4.00		Ice	-5.90	0.90	-5.31				-5.31
4/20/88	3.60	Snow				.24	3	Snow	.24	0.03	3	.36	3.36		Ice	-6.54	.90	-5.88		.09		
RESULTS FOR 1987 BALANCE YEAR:																		-5.88				-5.88
DATA FOR 1988 BALANCE YEAR:																							
STAKE UA88-38.3 (installed 4/20/88)																							
4/20/88	7.10	Snow				24		Snow	.24	0.03	3	0.36	6.86							0.09		0.09
9/2/88	.35	Ice											35		Ice	-6.51	0.90	-5.86				-5.86
Note: Very poor data: stake had fallen over and a hole 0.35 meters deep was observed.																							
RESULTS FOR 1988 BALANCE YEAR:																							no results
DATA FOR 1989 BALANCE YEAR:																							
STAKE UA89-38.3 (installed 4/15/89)																							
4/20/89	7.92	Snow				0.30	1	Snow	0.30		1	0.36	7.62							0.11		0.11
4/15/90	1.85	Snow				57	2	Snow	.57	0.04	2	.36	1.28		Ice	-6.34	.90	-5.71		.21		-5.71
RESULTS FOR 1989 BALANCE YEAR:																							-5.71

Table 2I. Mass balance, L-19 km site, Black Rapids Glacier

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter, d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error; Est., estimated, b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed; b(i), ice balance; b(f), firm balance; b(s), snow balance; b(k), internal accumulation–rain and snow melt water refrozen in the pore space of permeable firm in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ		b'ss		Material	Change	ρ	Ice	Firm	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.		Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1980 BALANCE YEAR:																							
STAKE 80-L19 (installed 3/28/80)																							
3/28/80	8.44	Snow				3.65	6	Snow	3.65	0.10	6	0.35		4.79							1.28		1.28
9/4/80	5.51	Snow			0.22			Snow	.22		1	.51		5.29							.11		
								Firm	.50		1	.51								0.26		.27	.53
3/23/81	7.73	Snow	0.35			2.64		Snow	2.64	.04	10	.35		5.09									
RESULTS FOR 1980 BALANCE YEAR:																				.26		.27	.53
DATA FOR 1981 BALANCE YEAR.																							
STAKE 80-L19 (continued)																							
3/23/81	7.73	Snow				2.64	10	Snow	2.64	0.04	10	0.35		5.09							0.92		0.92
9/22/81	5.87	Snow			0.52			Snow	.52		1	.20		5.35							.10		
								Firm	.28		1	.51								0.13		.21	.34
STAKE 81-L19 (installed 3/23/81)																							
3/23/81	8.28	Snow				2.64	10	Snow	2.64	.04	10	.35		5.64							.92		.92
9/22/81	6.20	Snow			.52			Snow	.52		1	.20		5.68							.10		
		Firm						Firm	.04		1	.51								.02		.21	.23
RESULTS FOR 1981 BALANCE YEAR: (average of stakes 80-L19 and 81-L19)																				.08		.21	.29
DATA FOR 1982 BALANCE YEAR:																							
STAKE 80-L19 (continued)																							
9/10/82	4.24	Snow				0.15	1	Snow	0.15		1	0.20		4.08							0.03		
STAKE 81-L19 (continued)																							
3/23/82	8.06	Snow	2.38					Snow	2.38		1	.35			5.68						.83		0.83
9/10/82	4.85	Snow				.15	1	Snow	.15		1	.20		4.70		Firm	-0.98	0.51		-0.50	.03		-.50
4/27/83	7.27	Snow				2.84	10	Snow	2.84	.09	10	.35		4.43							1.00		
STAKE 82-L19 (installed 3/23/82)																							
3/23/82	8.11	Snow	2.38					Snow	2.38			.35		5.73							.83		.83
9/10/82	4.73	Snow				.15		Snow	.15		1	.20		4.58		Firm	-1.15	.51		-.59	.03		-.69
4/27/83	7.43	Snow				2.84	10	Snow	2.84	.09	10	.35		4.59							1.00		
RESULTS FOR 1982 BALANCE YEAR:																				-.54			-.54
DATA FOR 1983 BALANCE YEAR																							
STAKE 82-L19 (continued)																							
4/27/83	7.43	Snow				2.84	10	Snow	2.84	0.09	10	0.35		4.59							1.00		1.00
9/9/83	4.27	Ice												4.27		Ice	-0.32	0.90	-0.28				-.28
3/17/84	6.71	Snow				2.74	10	Snow	2.74	.04	10	.35		3.97		Ice	-.61	.90	-.55		.96		
RESULTS FOR 1983 BALANCE YEAR:																			-.55				-.55
DATA FOR 1984 BALANCE YEAR:																							
STAKE 84-L19 (installed 3/17/84)																							
3/17/84	7.99	Snow				2.74	10	Snow	2.74	0.04	10	0.35		5.25							0.96		0.96
8/28/84	5.07	Snow				.04		Snow	.04		1	.20		5.03		Ice	-0.22	0.90	-0.20		.01		-.20
4/5/85	7.78	Snow				2.77	9	Snow	2.77	.02	9	.35		5.01		Ice	-.25	.90	-.22		.97		-.22
RESULTS FOR 1984 BALANCE YEAR:																			-.22				-.22

Table 2I, continued

Observations								Accumulation calculations						Summer surface b's		Ablation calculations			Mass balance results				
Date	Stake reading b'	Surface	Stake d(s)	Pit ρ	Pit d(s)	Probe d(s) Mean	n	Material	Thickness Mean	s.e.	n	ρ EstL		Obsv.	EstL	Material	Change	ρ EstL	Ice b(i)	Firn b(f)	Snow b(s)	Internal b(k)	Net b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	(g/cm³)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)	($m_{w.e.}$)
DATA FOR 1985 BALANCE YEAR:																							
STAKE 84-L19 (continued)																							
4/5/85	7.78	Snow				2.77		Snow	2.77	0.02	8	0.35		5.01							0.97		0.97
9/5/85	5.41	Snow			0.03			Snow	.03		1	.20		5.38	5.41						.01		
					.12			Sup. Ice	.12		1	.90								0.11			
					24			Firn	.24		1	.51								.12			.23
4/2/86	7.72	Snow				2.28		Snow	2.28	.01	10	.36		5.44	5.41						.80		
RESULTS FOR 1985 BALANCE YEAR:																				.23			.23
DATA FOR 1986 BALANCE YEAR																							
STAKE 84-L19 (continued)																							
4/2/86	7.72	Snow		0.35		2.28		Snow	2.28	0.01	10			5.44	5.41						0.80		0.80
9/25/86	4.69	Snow		.20		.30		Snow	.30	.02	12			4.39		Sup. Ice	-0.12	0.90		-0.11			
																Firn	- .24	.51		- .12			
																Ice	- .66	.90	-0.59				- .82
STAKE 86-L19 (installed 4/2/86)																							
4/2/86	8.25	Snow		.35		2.28		Snow	2.28	.01	10			5.97							.80		.80
9/25/86	5.30	Snow		.20		.30		Snow	.30	.02	12			5.00	4.93	Sup. Ice	- .12	.90		- .11			
																Firn	- .24	.51		- .12			
																Ice	- .68	.90	- .61				- .84
3/20/87	8.06	Snow		0.440		3.21		Snow	3.21		10			4.86	4.93						1.41		
RESULTS FOR 1986 BALANCE YEAR, (average of stakes 84-L19 and 86-L19)																			- .80	- .23			- .83
DATA FOR 1987 BALANCE YEAR																							
STAKE 86-L19 (continued)																							
3/20/87	8.06	Snow				3.21		Snow	3.21	0.05	10	0.35		4.85							1.12		1.12
4/20/88	8.30	Snow				3.19		Snow	3.19	.07	3	.35		5.11							1.12		
								Firn	.26		1	.51								0.13			.13
RESULTS FOR 1987 BALANCE YEAR:																				.13			.13

Table 2J. Mass balance, L-22 km site, Black Rapids Glacier

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter; d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error; Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed; b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation--rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Materia	Chang	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est.	Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1977 BALANCE YEAR																						
STAKE 77-L23 (installed 3/18/77)																						
3/18/77	9.94	Snow				2.75	4	Snow	2.75	0.07	4	0.32	7.20							0.88		0.88
3/21/78	7.53	Snow				2.07	5	Snow	2.07	.03	5	.32	5.46		Ice	-1.74	0.90	-1.56		.66		-1.56
RESULTS FOR 1977 BALANCE YEAR																		-1.56				-1.56
DATA FOR 1978 BALANCE YEAR																						
STAKE 78-L22 (installed 3/21/78)																						
3/21/78	8.08	Snow				2.20	5	Snow	2.20	0.03	5	0.32	5.88							0.70		0.70
3/30/79	4.91	Snow				1.97	10	Snow	1.97	.03	10	.32	2.94		Ice	-2.94	0.90	-2.64		.63		-2.64
RESULTS FOR 1978 BALANCE YEAR																		-2.64				-2.64
DATA FOR 1979 BALANCE YEAR																						
STAKE 78-L22 (continued)																						
3/30/79	4.91	Snow				1.97	10	Snow	1.97	0.03	10	0.32	2.94							0.63		0.63
RESULTS FOR 1979 BALANCE YEAR:																						no results
DATA FOR 1980 BALANCE YEAR:																						
STAKE 80-L22 (installed 3/28/80)																						
3/28/80	8.97	Snow				2.66	10	Snow	2.66	0.03	10	0.32	6.31							0.85		0.85
9/4/80	4.89	Snow				.07	10	Snow	.07	.01	10	.20	4.83	4.81	Ice	-1.50	0.90	-1.35		.01		-1.35
3/23/81	6.64	Snow				1.80	10	Snow	1.80	.02	10	.32	4.84	4.81						.58		
RESULTS FOR 1980 BALANCE YEAR																		-1.35				-1.35
DATA FOR 1981 BALANCE YEAR																						
STAKE 80-L22 (continued)																						
3/23/81	6.64	Snow				1.80	10	Snow	1.80	0.02	10	0.32	4.84	4.81						0.58		0.58
6/22/81	5.10	Snow				.35	9	Snow	.35	.04	9	.50	4.75	4.81						.17		.17
9/22/81	3.15	Snow				.40	1	Snow	.40		1	.20	2.75		Ice	-2.08	0.90	-1.85		.08		-1.85
STAKE 81-L22 (installed 3/23/81)																						
3/23/81	8.27	Snow				1.80	10	Snow	1.80	.02	10	.32	6.47	6.44						.58		.58
6/22/81	6.75	Snow				.35	9	Snow	.35	.04	9	.50	6.40	6.44						.17		.17
9/22/81	4.80	Snow				.40	1	Snow	.40		1	.20	4.40	4.39	Ice	-2.05	.90	-1.84		.08		-1.84
3/23/82	5.94	Snow				1.56	10	Snow	1.56	.02	10	.32	4.38	4.38						.50		
RESULTS FOR 1981 BALANCE YEAR: (average of stakes 80-L22 and 81-L22)																		-1.85				-1.85
DATA FOR 1982 BALANCE YEAR:																						
STAKE 81-L22 (continued)																						
3/23/82	5.94	Snow				1.56	10	Snow	1.56	0.02	10	0.32	4.38							0.50		0.50
9/11/82	2.04	Ice											2.04		Ice	-2.34	0.90	-2.11				-2.11
4/22/83	3.85	Snow				1.98	10	Snow	1.98	.02	10	.32	1.87		Ice	-2.51	.90	-2.26		.63		
STAKE 82-L22 (installed 3/23/82)																						
3/23/82	9.52	Snow				1.56	10	Snow	1.56	.02	10	.32	7.96							.50		.50
9/11/82	5.33	Ice											5.33		Ice	-2.63	.90	-2.37				-2.37
4/22/83	7.20	Snow				1.98	10	Snow	1.98	.02	10	.32	5.22		Ice	-2.74	.90	-2.47		.63		
RESULTS FOR 1982 BALANCE YEAR: (average of stakes 81-L22 and 82-L22)																		-2.37				-2.37

Table 2J, continued

Observations								Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Materia	Chang	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est	Obsv	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1983 BALANCE YEAR:																						
STAKE 83-L22 (installed 4/22/83)																						
4/22/83	10.21	Snow				1.98	10	Snow	1.98	0.02	10	0.32	8.23							0.63		0.63
9/8/83	6.11	Snow				.21	17	Snow	21	02	17	.20	5.90	5.94	Ice	-2.29	0.90	-2.06		.04		-2.06
3/17/84	7.96	Snow				1.97	10	Snow	1.97	.04	10	.32	5.99	5.94						.63		
RESULTS FOR 1983 BALANCE YEAR:																		-2.06				-2.06
DATA FOR 1984 BALANCE YEAR:																						
STAKE 83-L22 (continued)																						
3/17/84	7.96	Snow				1.97	10	Snow	1.97	0.04	10	0.32	5.99	5.94						0.63		0.63
8/28/84	4.12	Ice											4.12		Ice	-1.82	0.90	-1.64				-1.64
4/5/85	5.91	Snow				1.96	10	Snow	1.96	.01	10	32	3.95		Ice	-1.99	90	-1.79		63		
RESULTS FOR 1984 BALANCE YEAR:																		-1.79				-1.79
DATA FOR 1985 BALANCE YEAR																						
STATE 83-L22 (continued)																						
4/5/85	5.91	Snow				1.98	10	Snow	1.96	0.01	10	0.32	3.95							0.63		0.63
9/11/85	2.48	Ice											2.48		Ice	-1.47	0.90	-1.32				-1.32
STAKE 85-L22 (installed 4/5/85)																						
4/5/85	9.88	Snow				1.96	10	Snow	1.96	01	10	.32	7.92							.63		.63
9/11/85	6.22	Ice											6.22	6.24	Ice	-1.68	90	-1.51				-1.51
4/2/86	7.98	Snow				1.72	10	Snow	1.72	.08	10	32	6.26	6.24						.55		
RESULTS FOR 1985 BALANCE YEAR: (average of stakes 83-L22 and 85-L22)																		-1.42				-1.42
DATA FOR 1986 BALANCE YEAR.																						
STAKE 85-L22 (continued)																						
4/2/86	7.98	Snow				1.72	10	Snow	1.72	0.06	10	0.32	6.26	6.24						0.55		0.55
10/7/86	4.09	Snow				.36	14	Snow	36	.02	14	20	3.73		Ice	-2.51	0.90	-2.26		.07		-2.26
RESULTS FOR 1986 BALANCE YEAR.																		-2.26				-2.26
DATA FOR 1987 BALANCE YEAR:																						
STAKE 87-L22 (installed 3/20/87)																						
3/20/87	7.92	Snow				2.38	15	Snow	2.38	0.05	15	0.32	5.54							0.76		0.76
8/27/87	3.91	Ice											3.91	4.17	Ice	-1.37	0.90	-1.23				-1.23
4/14/88	6.36	Snow				1.93	3	Snow	1.93	06	3	.32	4.43	4.17						.62		
RESULTS FOR 1987 BALANCE YEAR:																		-1.23				-1.23
DATA FOR 1988 BALANCE YEAR.																						
STAKE 87-L22 (continued)																						
4/14/88	6.36	Snow				1.93	3	Snow	1.93	0.06	3	0.32	4.43	4.17						0.62		0.62
9/2/88	1.45	Snow				.03	1	Snow	.03		1	20	1.42	1.43	Ice	-2.74	0.90	-2.47		.01		-2.47
4/22/89	3.27	Snow				1.84	1	Snow	1.84		1	.32	1.43	1.43						59		
RESULTS FOR 1988 BALANCE YEAR:																		-2.47				-2.47

Table 3. Example mass balance calculation from the ablation area, 14 km site, 1983

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter, d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error; Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed. b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation--rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est	Obsv	Est			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1976 BALANCE YEAR																						
STAKE 75-14 (continued)																						
3/24/76	8.46	Snow				2.23	5	Snow	2.23	0.01	5	0.34	6.23							0.76		0.76
9/13/76	5.31	Snow				.27	1	Snow	.27		1	.20	5.04	4.97	Ice	-1.26	0.90	-1.13		.05		-1.13
3/19/77	8.00	Snow				3.09	3	Snow	3.09	.01	3	.34	4.91	4.97						1.05		
STAKE 76-14 (installed 3/24/76)																						
3/24/76	8.10	Snow				2.23	5	Snow	2.23	.01	5	.34	5.87							.76		.76
9/13/76	4.92	Snow				.27	1	Snow	.27		1	.20	4.65	4.71	Ice	-1.16	.90	-1.04		.05		-1.04
3/19/77	7.87	Snow				3.09	3	Snow	3.09	.01	3	.34	4.78	4.71						1.05		
RESULTS FOR 1976 BALANCE YEAR:(average of stakes 75-14 and 76-14)																		-1.09				-1.09

Table 4. Example mass balance calculation from the ablation area, 20 km site, 1975

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters, ρ, density; g/cm³, grams per cubic centimeter, d(s), depth of snow, Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error; Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed; b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation--rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations					Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ	b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e.	n	Est	Obsv.	Est			Est	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)	(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
DATA FOR 1975 BALANCE YEAR:																						
STAKE 75-20 (installed 3/2/75)																						
3/2/75	9.90	Snow				1.45	10	Snow	1.45	.03	10	.32	8.46							.46		.46
8/25/75	6.05	Ice											6.05		Ice	-2.41	0.90	-2.16				-2.16
3/24/76	7.07	Snow				1.28	8	Snow	1.28	.03	8	.32	5.79		Ice	-2.68	.90	-2.40		.41		-2.40
RESULTS FOR 1975 BALANCE YEAR:																		-2.40				-2.40

Table 5. Example mass balance calculation from the accumulation area, 8 km site, 1980

[m/d/y, month/day/year; b', height of surface on stake, measured relative to base of stake; m, meters; ρ, density; g/cm³, grams per cubic centimeter, d(s), depth of snow; Stake d(s) is calculated by subtracting a previously observed summer surface height (b'ss) from b'; Probe d(s) is measured by forcing a thin probe rod through the snow pack until it is stopped by the hard summer surface; n, number of observations; s.e., standard error; Est., estimated; b'ss, height of summer surface on stake, measured relative to base of stake; Obsv., observed; b(i), ice balance; b(f), firn balance; b(s), snow balance; b(k), internal accumulation--rain and snow melt water refrozen in the pore space of permeable firn in the accumulation area (Trabant and Mayo, 1985); b_n, net mass balance; m_{we}, meters water equivalent; Sup. ice, superimposed ice]

Observations								Accumulation calculations						Summer surface		Ablation calculations			Mass balance results				
Date	Stake reading		Stake	Pit		Probe d(s)		Material	Thickness			ρ		b'ss		Material	Change	ρ	Ice	Firn	Snow	Internal	Net
	b'	Surface	d(s)	ρ	d(s)	Mean	n		Mean	s.e	n	Est		Obsv.	Est.			Est.	b(i)	b(f)	b(s)	b(k)	b_n
m/d/y	(m)	material	(m)	(g/cm³)	(m)	(m)			(m)	(m)		(g/cm³)		(m)	(m)		(m)	(g/cm³)	(m_{we})	(m_{we})	(m_{we})	(m_{we})	(m_{we})
												DATA FOR 1980 BALANCE YEAR:											
STAKE 78-8 (continued)																							
3/27/80	8.33	Snow				3.11	5	Snow	3.11	0.01	5	0.36		5.22							1.12		1.12
9/4/80	6.83	Snow			0.32			Snow	.32		1	.26		6.51							.08		
								Firn	1.29		1	.51								0.68		0.27	.93
RESULTS FOR 1980 BALANCE YEAR:																				.68		.27	.93

Table 6. Uncertainties in mass balance quantities

[m, meters; g/cm³, grams per cubic centimeter; °C, degree Celsius]

Quantity	Estimated uncertainty	Comments
Stake reading, *(b')*		
On snow surface	±0.02 m	Snow surface is usually smooth.
On ice surface	±0.10 m	Ice surface is rough and uneven. *b'* is a visual average of the ice surface height.
Snow or firn density		
Estimated (snow)	±0.04 g/cm³	(≈15 percent) Most snow and firn densities were estimated.
Estimated (firn)	±0.1 g/cm³	(≈20 percent)
Observed in pit	±0.005 g/cm³	(1.5 percent) See description of snow pit uncertainties in the appendix "Snow Pit Data"
Depth of snow		
Probing	Standard error	Reported in the 9th column of the mass balance data tables.
Pit	Standard deviation	A single observation on an uneven surface. Typically 0.05-0.20 m.
Stake firn depth	±0.15 m	Firn compaction and stake slip can move the stake relative to the summer surface.
Summer surface temperature		
Observed	±1°C	Reading from a dial-type thermometer.
Calculated	±1-3°C	Error associated with extrapolating summer surface temperatures. See section "Temperatures at the Summer Surface".
Internal accumulation estimate	±10 percent	Error reported by Trabant and Mayo (1985).

Table 7. Combined uncertainties for mass balance site data: Examples of typical situations

[These terms are defined in section "Mass Balance Data Tables": b', stake height reading; d(s), snow depth; d(f), firn depth; s.e., standard error; ρ, density; ss, summer surface; m, meters; T, temperature; °C, degree Celsius; b(k), internal accumulation]

Area	First observation	Second observation	First observation uncertainties	Second observation uncertainties	Combined uncertainty
Ablation	Spring, on snow surface	Fall, on ice surface	b': ±0.02 m, d(s): s.e.≈±0.03 m	b': ±0.10 m, d(s): s.e.≈±0.03 m	±0.11 m
Ablation	Spring, on snow surface	Fall, on snow surface	b': ±0.02 m, d(s): s.e.≈±0.03 m	b': ±0.02 m, d(s): s.e.≈±0.03 m	±0.05 m
Accumulation	Spring, on snow surface	Fall, on snow surface	b': ±0.02 m, d(s): s.e.≈±0.03 m	b': ±0.02 m, d(s) in pit: ±0.10 m d(f): stake depth: ±0.15 m, ρ(firn): ±10 percent, T(ss): calc. ±2°C, b(k): ±10 percent	For 1.0 m of firn: 28 percent (±0.28 m), For 2.0 m of firn: 22 percent (±0.44 m)

Table 8. Additional snow depth measurements, Black Rapids Glacier

[Snow depths were measured in pits or by probing. Locations refer to centerline coordinates (see "Coordinate Systems" section) and were determined by estimating location on a map. Locations are accurate to 200 meters. km, kilometers; m, meters; g/cm³, grams per cubic centimeter]

Date	Location	Type	Data
8/27/70	3.6 km	Snow depth	0.80 m
8/27/70	8.9 km	Snow depth	0.60 m
8/27/70	8.9 km	Firn depth	1.65 m
8/27/70	13.0 km	Snow depth	0.10 m
8/27/70	13.0 km	Firn depth	0.80 m
4/23/72	6.3 km	Snow depth	3.90 m
4/23/72	9.7 km	Snow depth	3.02 m
4/23/72	12.6 km	Snow depth	2.25 m
4/23/72	16.0 km	Snow depth	1.98 m
4/23/72	19.0 km	Snow depth	1.53 m
4/23/72	19.0 km	Snow density	0.33 g/cm³
4/23/72	22.2 km	Snow depth	1.66 m
4/23/72	25.8 km	Snow depth	1.50 m
4/23/72	29.1 km	Snow depth	1.59 m
4/23/72	32.0 km	Snow depth	1.32 m
4/23/72	37.0 km	Snow depth	1.10 m
4/23/72	39.3 km	Snow depth	0.69 m
4/23/72	40.5 km	Snow depth	0.47 m
4/23/72	L-21 km	Snow depth	1.82 m
4/23/72	L-23 km	Snow depth	1.68 m

Table 9A. Ice velocity: 2 km site, Black Rapids Glacier

[Speeds are plotted in figure 3A. The coordinates for the base of the stake (X, Y, and Z) are reported in the local coordinate system (see "Coordinate Systems" section). Displacement is the length of the three-dimensional vector representing the net displacement of the base of the stake between the measurement dates. Seasonal speed is the speed measured between consecutive observations. Flow azimuth is measured relative to the positive y-axis (north) in the local coordinate system, positive clockwise. Vertical displacement and speed are reported separately. (Vertical displacement is included in the displacement and seasonal speed.) Annual speed is the speed over a period of approximately 1 year. Whenever possible, annual speed is calculated between consecutive spring observations. m, meters; m/yr, meters per year; —, no data]

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)	Annual speed (m/yr)
3/18/77	77-2	12023.6	2788.2	2227.6	—	—	—	—	—	—	—
9/23/77	77-2	12006.2	2789.0	2221.3	189	27.1	52.7	320.0	-6.3	-12.2	—
3/22/78	77-2	11996.7	2808.8	2217.4	180	22.0	44.8	334.6	-3.9	-8.0	49.4
3/27/80	80-2	12100.3	2746.3	2233.0	—	—	—	—	—	—	—
9/04/80	80-2	12090.9	2766.0	2228.6	161	21.8	49.7	334.4	-4.5	-10.2	—
3/22/81	80-2	12078.7	2788.9	2223.9	199	25.9	47.8	331.9	-4.6	-8.6	49.4
9/10/81	80-2	12067.0	2814.6	2218.0	172	28.2	60.3	335.6	-5.9	-12.6	—
3/24/82	80-2	12053.6	2840.3	2212.5	195	29.0	54.6	332.4	-5.5	-10.4	58.2
9/10/82	80-2	12045.4	2864.0	2208.4	170	25.1	54.1	341.0	-4.1	-8.8	—
3/24/82	82-2	12056.9	2726.3	2231.1	—	—	—	—	—	—	—
9/10/82	82-2	12047.9	2747.4	2227.1	170	23.3	50.3	337.0	-4.0	-8.7	—
3/16/84	84-2A	12027.2	2745.2	2230.2	—	—	—	—	—	—	—
8/28/84	84-2A	12017.7	2764.7	2226.3	165	21.7	48.3	334.2	-3.9	-8.7	—
3/16/84	84-2B	12024.4	2743.4	2230.0	—	—	—	—	—	—	—
8/28/84	84-2B	12014.7	2762.9	2226.2	165	22.1	49.3	333.7	-3.8	-8.5	—

Table 9B. Ice velocity: 4 km site, Black Rapids Glacier

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)	Annual speed (m/yr)
7/24/73	73-4	11352.5	4779.4	2024.2	---	---	---	---	---	---	---
3/27/74	73-4	11325.0	4818.3	2017.2	246	48.2	71.8	324.8	-7.0	-10.4	---
7/22/74	73-4	11311.3	4837.1	2014.3	117	23.4	73.6	323.8	-3.0	-9.3	72.1
8/28/75	73-4	11271.7	4894.7	2007.9	402	70.2	---	325.5	-6.3	-5.8	63.9
3/24/76	73-4	11251.8	4923.1	2005.4	209	34.9	61.2	324.7	-2.5	-4.4	---
9/13/76	73-4	11235.5	4948.1	2002.4	173	30.0	63.6	327.2	-3.0	-6.3	62.1
2/27/75	75-4	11228.0	4727.4	2015.9	---	---	---	---	---	---	---
8/28/75	75-4	11209.3	4754.5	2011.8	182	32.9	66.4	325.4	-4.1	-8.3	---
9/13/76	75-4	11170.9	4811.3	2005.9	382	68.5	---	325.9	-5.9	-5.6	65.6
3/18/77	77-4	11225.8	4700.4	2021.5	---	---	---	---	---	---	---
9/23/77	77-4	11204.7	4731.2	2017.5	189	37.5	72.9	325.6	-4.0	-7.7	---
3/18/78	77-4	11187.3	4756.6	2015.2	176	30.8	64.3	325.7	-2.3	-4.8	88.6
10/23/78	77-4	11165.6	4789.2	2012.9	219	39.2	65.6	326.3	-2.4	-4.0	---
3/28/79	77-4	11151.0	4810.9	2009.8	156	26.4	62.2	325.9	-3.0	-7.1	64.0
3/28/79	79-4	11224.0	4699.5	2019.0	---	---	---	---	---	---	---
8/23/79	79-4	11207.2	4724.2	2014.7	148	29.9	74.2	325.8	-4.3	-10.7	---
9/04/80	79-4	11170.3	4779.0	2008.9	378	66.0	0.0	326.1	-5.8	-5.6	63.9
3/27/80	80-4	11237.7	4663.4	2027.0	---	---	---	---	---	---	---
9/04/80	80-4	11219.7	4689.6	2021.8	161	32.2	73.4	325.5	-5.2	-12.0	---
3/22/81	80-4	11198.7	4720.8	2018.1	199	37.8	69.7	326.0	-3.7	-6.9	71.1
9/10/81	80-4	11179.3	4749.6	2014.2	172	34.9	74.6	326.0	-3.9	-8.3	---
3/24/82	80-4	11158.2	4781.1	2012.0	195	38.0	71.5	326.3	-2.2	-4.1	72.7
9/10/82	80-4	11139.8	4809.0	2009.1	170	33.5	72.4	326.6	-3.0	-6.4	---
3/24/82	82-4	11221.3	4683.2	2026.3	---	---	---	---	---	---	---
9/10/82	82-4	11200.5	4713.3	2021.2	170	36.9	79.7	325.4	-5.1	-11.0	---
4/23/83	82-4	11175.5	4750.3	2016.9	225	44.7	72.8	325.9	-4.3	-7.1	75.8
9/18/83	82-4	11158.7	4774.5	2014.6	148	29.5	73.2	325.3	-2.3	-5.6	---
3/16/84	82-4	11140.6	4802.4	2012.3	180	33.3	67.9	327.0	-2.3	-4.7	70.2
3/16/84	84-4A	11244.1	4671.9	2026.3	---	---	---	---	---	---	---
8/28/84	84-4A	11223.3	4704.0	2020.1	165	38.7	86.2	327.1	-6.3	-14.0	---
4/04/85	84-4A	11201.2	4737.0	2016.3	219	40.0	67.0	326.1	-4.8	-8.0	75.0
9/12/85	84-4A	11181.8	4763.8	2011.7	161	33.3	76.0	324.3	-3.6	-8.1	---
4/03/86	84-4A	11159.9	4793.7	2009.7	203	37.1	67.1	323.8	-2.0	-3.6	70.8
9/25/86	84-4A	11141.5	4821.9	2006.7	175	33.8	70.9	326.8	-3.0	-6.4	---
3/16/84	84-4B	11238.1	4669.9	2025.8	---	---	---	---	---	---	---
8/28/84	84-4B	11217.9	4700.4	2019.6	165	37.1	82.6	326.5	-6.2	-13.8	---
4/04/85	84-4B	11194.5	4733.6	2014.7	219	40.9	68.5	324.9	-5.0	-8.3	74.4
9/12/85	84-4B	11175.5	4760.4	2011.3	161	33.0	75.3	324.6	-3.3	-7.6	---
4/03/86	84-4B	11154.5	4792.0	2009.1	203	38.1	68.8	326.3	-2.2	-4.0	71.4
9/25/86	84-4B	11135.4	4819.9	2006.2	175	33.9	71.2	325.7	-2.9	-6.1	---
4/03/86	86-4	11229.9	4696.2	2022.8	203	---	---	---	---	---	---
9/25/86	86-4	11209.3	4726.1	2017.4	175	36.3	76.2	325.4	-5.5	-11.5	---
3/18/87	86-4	11189.8	4755.2	2013.7	174	35.1	74.1	326.2	-3.8	-7.7	75.5

Table 9C. Ice velocity: 8 km site, Black Rapids Glacier

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)	Annual speed (m/yr)
7/15/73	73-8	9126.7	7794.5	1895.1	---	---	---	---	---	---	---
3/27/74	73-8	9117.8	7826.8	1894.0	255	33.5	48.1	344.6	-1.1	-1.6	---
7/22/74	73-8	9111.9	7845.1	1893.7	117	19.2	60.4	342.1	-0.3	-0.9	51.8
3/27/74	74-8	9117.8	7826.8	1891.7	---	---	---	---	---	---	---
7/22/74	74-8	9111.9	7845.1	1891.4	117	19.2	60.4	107.9	-0.3	-1.0	---
2/28/75	74-8	9104.7	7870.3	1890.7	221	26.3	43.6	105.9	-0.7	-1.1	49.3
8/28/75	74-8	9097.5	7894.5	1889.9	181	25.3	51.3	106.7	-0.8	-1.6	---
3/24/76	74-8	9089.7	7920.6	1889.3	209	27.3	47.8	106.7	-0.7	-1.2	49.3
9/13/76	74-8	9082.2	7944.5	1888.5	173	25.0	53.1	107.3	-0.7	-1.5	---
3/18/77	74-8	9076.1	7966.3	1888.1	186	22.7	44.7	105.6	-0.5	-0.9	48.6
9/23/77	74-8	9068.2	7991.5	1887.4	189	26.5	51.4	107.5	-0.7	-1.3	---
3/22/78	74-8	9062.4	8011.4	1887.2	180	20.7	42.1	106.3	-0.2	-0.4	46.7
10/23/78	74-8	9053.6	8038.2	1886.6	215	28.2	48.2	108.0	-0.6	-1.1	---
9/23/77	77-8	9034.7	8063.9	1889.1	---	---	---	---	---	---	---
3/22/78	77-8	9029.3	8083.8	1888.9	180	20.6	42.0	343.7	-0.2	-0.4	---
3/22/78	78-8	9087.3	8076.1	1885.0	---	---	---	---	---	---	---
10/23/78	78-8	9079.2	8103.9	1884.1	215	29.0	49.5	343.9	-0.9	-1.6	---
3/28/79	78-8	9073.5	8122.5	1883.9	156	19.4	45.7	342.8	-0.2	-0.4	47.8
8/23/79	78-8	9066.4	8145.5	1882.9	148	24.1	59.8	342.9	-1.1	-2.6	---
3/27/80	78-8	9059.4	8170.0	1882.4	217	25.5	43.0	344.1	-0.5	-0.8	49.7
9/4/80	78-8	9052.4	8193.0	1881.7	161	24.1	55.0	343.1	-0.7	-1.5	---
3/22/81	78-8	9045.1	8217.2	1881.6	199	25.2	46.5	343.1	-0.1	-0.3	50.2
6/22/81	78-8	9040.6	8232.2	1881.0	92	15.7	62.8	343.2	-0.6	-2.4	---
3/22/81	81-8	9082.6	8093.3	1887.0	---	---	---	---	---	---	---
6/22/81	81-8	9078.2	8107.2	1886.4	92	14.7	58.8	342.3	-0.6	-2.4	---
9/10/81	81-8	9073.9	8119.6	1885.9	80	13.2	60.8	341.0	-0.5	-2.4	---
3/24/82	81-8	9065.5	8145.3	1885.4	195	27.0	50.9	341.8	-0.4	-0.8	53.5
9/10/82	81-8	9058.0	8172.4	1884.7	170	28.1	60.7	344.5	-0.8	-1.7	---
4/21/83	81-8	9049.4	8203.4	1884.3	223	32.2	52.9	344.6	-0.4	-0.6	56.1
4/21/83	83-8	9122.7	8011.3	1889.9	---	---	---	---	---	---	---
9/8/83	83-8	9115.6	8033.7	1889.1	140	23.5	61.7	342.6	-0.8	-2.0	---
3/17/84	83-8	9107.1	8059.6	1888.2	191	27.3	52.4	341.7	-0.9	-1.8	56.2
8/28/84	83-8	9099.2	8087.2	1887.2	164	28.7	64.4	344.1	-1.0	-2.3	---
4/4/85	83-8	9089.4	8117.3	1886.6	219	31.7	53.0	342.0	-0.6	-1.0	57.7
9/11/85	83-8	9081.8	8143.0	1885.7	160	26.7	61.4	343.4	-0.9	-2.0	---
4/3/86	83-8	9073.9	8172.3	1885.0	204	30.4	54.6	344.8	-0.7	-1.3	57.4
4/3/86	86-8	9082.8	8077.3	1890.3	---	---	---	---	---	---	---
9/25/86	86-8	9073.7	8105.2	1889.2	175	29.3	61.5	341.8	-1.1	-2.2	---
3/18/87	86-8	9066.2	8129.8	1888.7	174	25.8	54.3	343.2	-0.5	-1.1	57.8
8/27/87	86-8	9058.4	8156.4	1887.6	162	27.7	62.8	343.5	-1.0	-2.3	---
4/21/88	86-8	9048.1	8190.1	1887.0	238	35.3	54.3	343.0	-0.6	-1.0	57.6
4/19/90	UA90-8	9080.8	8063.9	1889.3	---	---	---	---	---	---	---
5/1/91	UA90-8	9066.1	8112.0	1887.8	377	50.3	---	343.0	-1.5	-1.5	48.8
5/4/92	UA90-8	9051.5	8162.6	1887.5	369	52.7	---	343.9	-0.2	-0.2	52.3
9/23/92	UA90-8	9044.6	8185.4	1886.6	142	23.8	61.6	343.0	-1.0	-2.5	---

Table 9D. Ice velocity: 14 km site, Black Rapids Glacier

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)	Annual speed (m/yr)
7/21/74	73-14	8987.5	13163.6	1709.8	—	—	—	—	—	—	—
3/01/75	73-14	9015.0	13171.2	1709.7	223	28.6	47.0	74.5	-0.2	-0.3	—
8/26/75	73-14	9043.7	13179.0	1709.4	178	29.7	61.3	74.8	-0.2	-0.5	53.2
3/01/75	75-14	8972.0	13155.5	1705.5	—	—	—	—	—	—	—
8/26/75	75-14	9000.6	13164.3	1705.1	178	29.9	61.6	73.0	-0.4	-0.8	—
3/24/76	75-14	9025.6	13170.9	1704.9	211	25.8	44.9	75.1	-0.2	-0.4	52.4
9/13/76	75-14	9054.4	13178.4	1704.8	173	29.8	63.2	75.4	-0.1	-0.3	—
3/18/77	75-14	9073.9	13183.8	1704.8	186	20.2	40.0	74.7	0.0	0.1	51.0
3/24/76	76-14	8740.6	13111.2	1713.8	—	—	—	—	—	—	—
9/13/76	76-14	8766.7	13120.6	1713.6	173	27.7	58.7	70.1	-0.2	-0.4	—
3/18/77	76-14	8787.1	13127.3	1713.6	186	21.5	42.4	71.9	0.0	0.0	50.1
9/23/77	76-14	8814.9	13136.8	1713.3	189	29.4	57.1	71.1	-0.3	-0.5	—
3/18/78	76-14	8831.2	13142.8	1713.3	176	17.3	36.0	70.0	-0.1	-0.1	46.8
9/24/78	76-14	8858.0	13151.4	1713.0	190	28.3	54.6	72.1	-0.3	-0.6	—
3/28/79	76-14	8876.4	13157.1	1713.2	185	19.2	38.2	72.9	0.2	0.4	46.4
3/28/79	79-14	8765.4	13112.2	1713.2	—	—	—	—	—	—	—
8/23/79	79-14	8791.1	13121.1	1712.6	148	27.2	67.5	70.9	-0.6	-1.5	—
3/26/80	79-14	8814.5	13129.5	1712.7	216	24.9	42.2	70.3	0.1	0.2	52.3
9/04/80	79-14	8841.0	13138.2	1712.3	162	27.9	63.2	71.8	-0.4	-0.9	—
3/22/81	79-14	8862.5	13145.5	1712.5	199	22.8	41.9	71.2	0.2	0.4	51.3
6/22/81	79-14	8879.2	13150.5	1712.3	92	17.4	69.8	73.6	-0.3	-1.0	—
9/10/81	79-14	8894.0	13155.1	1711.9	80	15.5	71.4	72.6	-0.3	-1.5	—
3/25/82	79-14	8916.2	13161.8	1712.3	196	23.2	43.4	73.2	0.4	0.7	51.3
9/10/82	79-14	8947.4	13171.2	1712.4	169	32.6	70.9	73.3	0.1	0.2	—
3/25/82	82-14	8762.5	13182.3	1713.7	—	—	—	—	—	—	—
9/10/82	82-14	8793.2	13192.9	1713.9	169	32.5	70.6	70.9	0.2	0.4	—
4/21/83	82-14	8823.3	13203.3	1713.6	223	31.8	52.4	70.9	-0.3	-0.5	60.1
9/08/83	82-14	8850.3	13212.1	1713.1	140	28.4	74.6	71.9	-0.5	-1.3	—
3/16/84	82-14	8876.3	13220.2	1713.0	190	27.3	52.7	72.8	-0.1	-0.2	61.8
4/05/85	82-14	8941.6	13239.7	1712.3	220	68.1	—	73.4	-0.8	-1.3	64.7
4/21/83	83-14	8757.2	13171.7	1715.1	—	—	—	—	—	—	—
9/08/83	83-14	8784.0	13180.9	1714.7	140	28.4	74.5	71.2	—	—	—
3/16/84	83-14	8809.7	13189.3	1714.6	190	27.0	52.1	71.9	-0.1	-0.2	61.4
8/28/84	83-14	8843.7	13199.9	1713.9	165	35.6	79.3	72.6	-0.7	-1.6	—
9/05/85	83-14	8907.6	13218.0	1712.7	373	66.4	—	74.2	-1.1	—	65.2
3/16/84	84-14	8762.3	13111.6	1713.1	—	—	—	—	—	—	—
8/28/84	84-14	8796.6	13123.0	1712.3	165	36.2	80.7	71.6	-0.8	-1.8	—
4/05/85	84-14	8828.3	13133.1	1712.2	220	33.2	55.4	72.3	0.0	-0.1	66.0
9/05/85	84-14	8861.2	13142.2	1711.1	153	34.1	81.9	74.6	-1.1	-2.6	—
4/04/86	84-14	8895.8	13154.7	1711.0	211	36.8	63.9	70.1	-0.1	-0.2	71.2
9/25/86	84-14	8933.5	13165.4	1710.1	174	39.3	82.9	74.1	-0.9	-1.8	—
4/04/86	86-14	8776.3	13126.7	1715.7	—	—	—	—	—	—	—
9/25/86	86-14	8813.9	13139.2	1715.1	174	39.6	83.7	71.5	-0.5	-1.1	—
3/20/87	86-14	8842.2	13147.6	1714.9	176	29.6	61.7	73.6	-0.2	-0.5	72.4
8/27/87	86-14	8878.4	13160.8	1714.3	160	38.5	88.4	69.9	-0.6	-1.3	—
4/21/88	86-14	8911.9	13167.9	1714.2	238	34.3	52.8	78.0	-0.2	-0.3	66.8
8/27/87	87-14	8815.7	13179.5	1713.5	—	—	—	—	—	—	—
4/21/88	87-14	8848.0	13187.3	1714.0	238	33.2	51.1	76.5	0.4	0.7	—
4/15/89	87-14	8905.3	13202.8	1713.5	359	59.4	—	74.9	-0.4	-0.4	60.6
5/23/90	87-14	8965.4	13220.5	1712.8	403	62.7	—	73.6	-0.7	-0.7	56.9
5/23/90	UA90-14	8782.2	13126.2	1716.1	—	—	—	—	—	—	—
5/01/91	UA90-14	8830.5	13140.6	1715.5	343	50.4	—	73.4	-0.6	-0.6	53.8
5/04/92	UA90-14	8885.0	13157.3	1715.0	369	57.0	—	73.0	-0.5	-0.5	56.6
5/04/92	92-14	8782.0	13150.5	1717.1	—	—	—	—	—	—	—
9/23/92	92-14	8809.3	13157.8	1715.7	142	28.4	73.4	75.0	-1.4	-3.5	—

Table 9E. Ice velocity: 20 km site, Black Rapids Glacier

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)	Annual speed (m/yr)
7/21/73	73-20	14823.1	13405.3	1510.6	—	—	—	—	—	—	—
7/21/74	73-20	14871.2	13404.0	1511.9	365	48.1	—	91.5	1.3	1.3	48.3
7/21/74	74-20	14871.2	13404.0	1508.9	—	—	—	—	—	—	—
3/02/75	74-20	14893.6	13405.1	1508.7	224	22.4	36.7	87.1	-0.2	-0.3	—
3/02/75	75-20	14855.4	13405.4	1503.2	—	—	—	—	—	—	—
8/25/75	75-20	14883.5	13404.0	1502.8	176	28.2	58.7	93.0	-0.4	-0.8	—
3/25/76	75-20	14901.8	13403.3	1503.6	213	18.3	31.6	92.1	0.8	1.3	43.7
9/13/76	75-20	14925.2	13402.8	1504.1	172	23.4	50.0	91.2	0.5	1.1	—
3/18/77	75-20	14939.5	13402.7	1504.5	186	14.3	28.2	90.4	0.5	0.9	38.6
3/18/77	77-20	14808.4	13407.2	1504.5	—	—	—	—	—	—	—
9/21/77	77-20	14833.6	13406.6	1505.2	187	24.3	47.6	91.4	0.7	1.3	0.0
3/18/78	77-20	14847.7	13406.3	1505.5	178	14.1	29.0	91.1	0.3	0.7	38.4
9/23/78	77-20	14870.6	13405.9	1505.7	189	22.9	44.5	91.1	0.2	0.4	0.0
3/29/79	77-20	14885.1	13405.6	1506.2	187	14.5	28.4	91.1	0.5	1.0	36.4
3/26/80	80-20	14779.0	13405.7	1502.5	—	—	—	—	—	—	—
9/04/80	80-20	14801.7	13405.3	1503.1	162	22.8	51.6	91.1	0.6	1.4	—
3/23/81	80-20	14818.9	13405.1	1503.8	200	17.2	31.6	90.6	0.6	1.2	40.4
6/22/81	80-20	14834.0	13405.2	1504.6	91	15.1	61.3	89.6	0.8	3.2	—
9/10/81	80-20	14845.2	13404.7	1504.4	80	11.2	51.8	92.2	-0.2	-0.9	0.0
3/23/81	81-20	14776.7	13400.1	1503.1	—	—	—	—	—	—	—
6/22/81	81-20	14790.7	13401.1	1503.7	91	14.0	56.9	86.2	0.6	2.2	—
9/10/81	81-20	14803.5	13399.9	1503.7	80	12.8	59.0	95.2	0.1	0.3	—
3/25/82	81-20	14820.7	13399.2	1504.1	196	17.3	32.3	92.2	0.3	0.7	39.8
9/10/82	81-20	14847.3	13398.8	1504.8	169	26.6	57.8	90.9	0.7	1.6	—
3/25/82	82-20	14773.3	13401.2	1501.8	—	—	—	—	—	—	—
9/10/82	82-20	14799.3	13401.1	1502.5	169	26.0	56.5	90.2	0.7	1.5	—
4/21/83	82-20	14823.6	13400.9	1503.5	223	24.3	40.0	90.4	1.0	1.6	47.0
9/08/83	82-20	14848.6	13400.3	1503.8	140	25.0	65.5	91.6	0.4	0.9	—
3/19/84	82-20	14868.5	13400.0	1504.8	193	19.9	37.9	90.8	1.0	2.0	49.3
4/21/83	83-20	14805.4	13405.8	1501.0	—	—	—	—	—	—	—
9/08/83	83-20	14829.7	13405.6	1501.4	140	24.3	63.8	90.4	0.4	1.0	—
3/19/84	83-20	14849.8	13405.3	1502.4	193	20.2	38.3	91.0	1.0	1.9	48.9
3/19/84	84-20	14784.1	13400.6	1500.3	—	—	—	—	—	—	—
8/28/84	84-20	14814.0	13400.3	1501.3	162	29.9	67.8	90.6	1.0	2.2	—
4/05/85	84-20	14839.0	13399.9	1502.2	220	25.1	41.8	91.1	1.0	1.6	52.6
9/11/85	84-20	14869.5	13399.2	1503.3	159	30.5	70.4	91.4	1.1	2.5	—
4/02/86	84-20	14894.5	13398.3	1505.0	203	25.1	45.4	91.9	1.7	3.0	56.2
9/25/86	84-20	14930.1	13398.0	1505.7	176	35.6	74.2	90.5	0.7	1.5	—
4/02/86	86-20	14822.2	13402.5	1503.1	—	—	—	—	—	—	—
9/25/86	86-20	14858.2	13402.5	1503.8	176	36.0	75.0	90.0	0.7	1.5	—
3/18/87	86-20	14880.5	13402.6	1505.2	174	22.3	47.1	89.6	1.4	3.0	60.9
8/27/87	86-20	14914.5	13401.4	1505.9	162	34.1	77.3	92.0	0.7	1.7	—
3/18/87	87-20	14786.9	13394.4	1507.0	—	—	—	—	—	—	—
8/27/87	87-20	14820.8	13393.4	1507.9	162	33.9	77.0	91.7	0.9	2.0	—
4/16/88	87-20	14848.1	13393.0	1509.0	233	27.3	43.0	91.0	1.1	1.8	56.8
4/15/89	87-20	14900.8	13392.1	1510.0	364	52.7	—	91.0	1.0	1.0	53.0
5/26/90	UA90-20	14785.4	13414.2	1504.6	—	—	—	—	—	—	—
5/01/91	UA90-20	14830.0	13413.7	1505.4	340	44.7	—	90.7	0.8	0.9	48.1
5/05/92	UA90-20	14879.6	13413.3	1507.2	370	49.7	—	90.5	1.8	1.8	49.1
9/23/92	UA90-20	14905.3	13413.2	1507.4	141	25.7	66.9	90.2	0.2	0.6	—
5/05/92	92-20	14786.9	13406.4	1504.0	—	—	—	—	—	—	—
9/23/92	92-20	14813.5	13407.1	1504.3	141	26.7	69.5	88.4	0.3	0.8	—

Table 9F. Ice velocity: 26 km site, Black Rapids Glacier

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)	Annual speed (m/yr)
7/21/74	74-26	20644.3	12226.6	1345.7	—	—	—	—	—	—	—
3/03/75	74-26	20670.2	12221.3	1344.9	225	26.5	43.1	101.5	-0.8	-1.2	—
3/03/75	75-26	20647.4	12245.5	1335.6	—	—	—	—	—	—	—
3/26/76	75-26	20690.8	12239.2	1336.5	389	43.8	—	98.4	0.9	0.9	41.2
9/13/76	75-26	20712.6	12234.7	1336.5	171	22.3	47.9	101.6	0.0	-0.1	—
3/16/77	75-26	20728.9	12232.3	1337.1	184	16.5	32.8	98.5	0.6	1.2	39.9
3/16/77	77-26	20701.1	12206.2	1332.7	—	—	—	—	—	—	—
9/20/77	77-26	20725.2	12202.8	1332.9	188	24.3	47.5	98.1	0.2	0.4	—
3/19/78	77-26	20740.6	12200.0	1333.5	180	15.7	32.1	100.4	0.6	1.3	39.8
3/19/78	78-26	20624.7	12250.0	1335.3	—	—	—	—	—	—	—
9/23/78	78-26	20648.4	12246.1	1335.6	188	24.0	46.9	99.3	0.2	0.4	—
3/28/79	78-26	20665.6	12243.7	1336.4	186	17.4	34.2	98.0	0.8	1.6	40.5
3/28/79	79-26	20653.8	12225.3	1332.5	—	—	—	—	—	—	—
8/23/79	79-26	20677.0	12221.8	1332.6	148	23.5	58.3	98.6	0.1	0.2	—
3/26/80	79-26	20697.7	12218.4	1333.0	216	21.0	35.6	99.1	0.5	0.8	44.7
3/26/80	80-26	20660.7	12224.2	1329.9	—	—	—	—	—	—	—
9/04/80	80-26	20681.5	12220.8	1330.3	162	21.1	47.9	99.1	0.4	0.9	—
3/24/81	80-26	20699.8	12218.0	1331.1	201	18.5	33.7	98.7	0.8	1.5	39.9
6/22/81	80-26	20712.7	12215.9	1331.6	90	13.1	53.8	99.4	0.5	1.8	—
3/24/81	81-26	20640.4	12226.6	1328.2	—	—	—	—	—	—	—
6/22/81	81-26	20653.4	12224.7	1328.7	90	13.1	53.8	98.4	0.5	2.0	—
9/22/81	81-26	20665.5	12223.1	1328.9	92	12.2	48.8	97.6	0.2	0.8	—
3/22/82	81-26	20681.7	12220.2	1329.6	181	16.5	33.5	100.1	0.6	1.3	42.2
3/22/82	82-26	20670.7	12206.2	1323.7	—	—	—	—	—	—	—
9/10/82	82-26	20694.2	12201.5	1324.2	172	24.0	51.2	101.3	0.5	1.2	—
4/20/83	82-26	20715.7	12197.8	1325.1	222	21.9	36.1	99.9	0.8	1.4	42.6
4/20/83	83-26	20658.2	12213.0	1324.4	—	—	—	—	—	—	—
9/08/83	83-26	20679.0	12208.6	1324.3	141	21.2	55.3	101.9	-0.1	-0.3	—
3/19/84	83-26	20697.2	12205.9	1325.6	193	18.5	35.1	98.5	1.3	2.4	43.5
3/19/84	84-26	20657.2	12210.9	1319.7	—	—	—	—	—	—	—
8/28/84	84-26	20681.0	12206.8	1320.4	162	24.2	54.8	99.9	0.7	1.5	—
4/05/85	84-26	20703.0	12203.6	1321.6	220	22.2	37.1	98.1	1.2	2.0	44.5
9/05/85	84-26	20727.1	12199.1	1322.0	153	24.5	58.9	100.7	0.5	1.1	—
4/09/86	84-26	20748.8	12195.7	1322.9	216	22.0	37.3	98.9	0.9	1.4	46.1
4/05/85	85-26	20660.3	12213.6	1316.5	—	—	—	—	—	—	—
9/05/85	85-26	20683.6	12210.0	1317.2	153	23.5	56.5	98.8	0.7	1.6	—
4/09/86	85-26	20705.5	12206.7	1318.1	216	22.2	37.7	98.5	0.9	1.6	45.4
10/07/86	85-26	20733.7	12200.8	1319.7	181	28.8	58.5	101.8	1.6	3.3	—
3/19/87	85-26	20751.0	12199.7	1320.4	163	17.4	39.1	93.5	0.7	1.5	49.1

Table 9G. Ice velocity: 32 km site, Black Rapids Glacier

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)	Annual speed (m/yr)
7/23/73	73-32-B	26418.5	10879.7	1141.2	—	—	—	—	—	—	—
3/31/74	73-32-B	26427.4	10877.7	1141.3	251	9.2	13.4	-12.7	0.2	0.2	—
3/31/74	74-32-B	26427.4	10877.7	1138.3	—	—	—	—	—	—	—
7/21/74	74-32-B	26433.4	10876.5	1140.4	112	6.4	21.2	-11.1	2.1	6.9	15.7
3/04/75	75-32.5	26538.6	10874.9	1129.0	—	—	—	—	—	—	—
8/25/75	75-32.5	26546.9	10873.4	1130.0	174	8.5	17.9	-10.4	1.0	2.0	—
3/26/76	75-32.5	26553.4	10871.3	1131.6	214	7.1	12.1	-17.8	1.6	2.8	14.6
3/26/76	76-32	26535.3	10867.6	1127.4	—	—	—	—	—	—	—
9/13/76	76-32	26543.0	10866.0	1127.9	171	7.8	16.8	-12.2	0.5	1.0	—
3/14/77	76-32	26548.2	10864.4	1128.9	182	5.5	11.1	-17.2	0.9	1.9	13.8
3/14/77	77-32	26521.5	10832.4	1126.7	—	—	—	—	—	—	—
9/20/77	77-32	26530.3	10830.5	1127.1	190	9.0	17.4	-12.2	0.4	0.8	—
3/23/78	77-32	26535.7	10829.2	1128.8	184	5.8	11.6	-13.6	1.7	3.3	14.4
3/23/78	78-32	26512.3	10834.7	1122.8	—	—	—	—	—	—	—
9/22/78	78-32	26520.1	10833.8	1123.9	183	7.9	15.8	-6.7	1.1	2.2	—
3/29/79	78-32	26525.5	10832.9	1124.9	188	5.6	10.9	-9.5	1.0	2.0	13.3
3/29/80	80-32	26529.3	10836.7	1115.1	—	—	—	—	—	—	—
9/04/80	80-32	26537.3	10835.2	1115.9	159	8.2	18.9	-10.7	0.8	1.8	—
3/24/81	80-32	26545.2	10833.8	1117.1	201	8.1	14.9	-10.4	1.2	2.1	16.6
3/24/81	81-32	26527.9	10834.2	1113.8	—	—	—	—	—	—	—
9/14/81	81-32	26535.3	10831.7	1115.0	174	7.9	16.6	-18.4	1.3	2.6	—
3/22/82	81-32	26541.8	10829.6	1116.1	189	7.0	13.5	-18.0	1.1	2.2	15.0
3/22/82	82-32	26524.9	10830.4	1110.2	—	—	—	—	—	—	—
9/11/82	82-32	26533.7	10828.9	1111.2	173	8.9	19.0	-9.7	1.0	2.1	0.0
4/20/83	82-32	26541.9	10826.6	1113.1	221	8.7	14.5	-15.7	1.8	3.0	16.3
4/20/83	83-32	26525.0	10831.2	1108.5	—	—	—	—	—	—	—
9/08/83	83-32	26531.5	10828.3	1109.5	141	7.1	18.6	-24.2	0.9	2.4	—
3/18/84	83-32	26538.1	10827.2	1110.7	192	6.8	13.1	-9.4	1.3	2.5	15.2
3/18/84	84-32	26515.2	10836.7	1101.1	—	—	—	—	—	—	—
8/28/84	84-32	26523.4	10832.0	1102.1	163	9.4	21.2	-29.5	0.9	2.1	—
4/05/85	84-32	26531.4	10829.9	1103.5	220	8.4	14.0	-14.9	1.5	2.4	16.8
9/05/85	84-32	26540.6	10827.0	1105.1	153	9.8	23.6	-17.6	1.5	3.7	—
4/05/85	85-32	26527.6	10840.4	1102.3	—	—	—	—	—	—	—
9/05/85	85-32	26535.2	10837.6	1103.9	153	8.3	20.0	-20.1	1.7	4.0	—
4/09/86	85-32	26543.6	10836.3	1104.8	216	8.6	14.5	-8.7	0.9	1.5	16.6
4/09/86	86-32	26526.8	10836.3	1103.1	—	—	—	—	—	—	—
10/07/86	86-32	26537.2	10832.7	1104.8	181	11.1	22.5	-19.2	1.7	3.5	—
3/19/87	86-32	26542.9	10830.6	1106.0	163	6.2	14.0	-20.2	1.2	2.7	18.4
3/19/87	87-32	26533.0	10837.4	1099.5	—	—	—	—	—	—	—
8/27/87	87-32	26541.5	10834.2	1100.8	161	9.2	20.9	-20.9	1.2	2.8	—

Table 9H. Ice velocity: 38 km site, Black Rapids Glacier

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)	Annual speed (m/yr)
3/06/75	75-38.8	32545.7	11205.0	942.6	—	—	—	—	—	—	—
8/26/75	75-38.8	32549.7	11207.0	943.4	173	4.6	9.7	63.5	0.9	1.8	—
3/26/76	75-38.8	32553.7	11209.0	944.2	213	4.5	7.7	63.1	0.8	1.3	8.6
3/14/77	77-38	32495.6	11255.6	938.4	—	—	—	—	—	—	—
9/20/77	77-38	32500.6	11258.6	938.4	190	5.9	11.4	59.1	0.0	0.0	—
3/29/79	79-38.3	32560.2	11248.4	923.8	—	—	—	—	—	—	—
8/23/79	79-38.3	32563.4	11250.4	924.5	147	3.8	9.5	57.9	0.6	1.6	—
3/29/80	79-38.3	32567.4	11252.6	925.5	219	4.7	7.8	61.4	1.0	1.6	8.5
3/29/80	80-38	32550.3	11232.2	916.8	—	—	—	—	—	—	—
9/04/80	80-38	32555.4	11234.1	917.7	159	5.4	12.5	69.6	0.9	—	—
3/24/81	80-38	32558.7	11235.5	918.5	201	3.7	6.7	67.3	0.8	—	9.3
3/24/81	81-38.3	32545.7	11225.8	912.6	—	—	—	—	—	—	—
9/14/81	81-38.3	32551.2	11228.4	913.5	174	6.2	13.0	64.5	0.9	2.0	—
3/22/82	81-38.3	32554.4	11229.7	914.3	189	3.6	7.0	67.5	0.8	1.5	9.8
3/22/82	82-38	32547.0	11229.0	907.2	—	—	—	—	—	—	—
9/11/82	82-38	32551.2	11231.7	908.0	173	5.0	10.6	56.9	0.8	—	—
4/20/83	82-38	32555.6	11233.5	909.4	221	5.0	8.3	67.7	1.4	—	9.2
4/20/83	83-38.3	32547.0	11227.1	903.3	—	—	—	—	—	—	—
9/08/83	83-38.3	32549.8	11229.9	904.2	141	4.0	10.5	45.2	0.8	2.1	—
3/18/84	83-38.3	32554.3	11231.6	905.0	192	4.9	9.3	69.1	0.9	1.7	9.5
3/18/84	84-38	32547.3	11239.3	894.4	—	—	—	—	—	—	—
8/29/84	84-38	32552.9	11240.8	895.1	164	5.8	13.1	75.2	0.8	—	—
9/05/85	84-38	32561.4	11244.1	896.9	372	9.3	9.2	69.0	1.8	—	9.2
4/06/86	84-38	32565.1	11245.6	898.0	213	4.2	7.2	67.6	1.0	—	—
9/05/85	85-38	32550.9	11234.4	894.6	—	—	—	—	—	—	—
4/06/86	85-38	32554.9	11235.8	895.7	213	4.4	7.6	70.6	1.0	1.8	—
4/06/86	86-38.3	32552.1	11230.2	891.1	—	—	—	—	—	—	—
3/19/87	86-38.3	32559.7	11233.1	892.9	347	8.4	8.8	69.4	1.8	1.9	8.9

Table 9I. Ice velocity: L-19 km site, Loket Tributary of the Black Rapids Glacier

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displace-ment (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displace-ment (m)	Vertical speed (m/yr)	Annual speed (m/yr)
3/28/80	80-L19	16348.2	7673.9	1651.6	---	—	---	---	---	---	---
9/04/80	80-L19	16352.5	7714.7	1650.2	160	41.1	94.3	6.1	-1.5	-3.4	---
3/23/81	80-L19	16358.4	7760.0	1648.4	200	45.7	83.8	7.4	-1.7	-3.2	88.2
9/22/81	80-L19	16366.4	7808.5	1645.5	183	49.3	98.9	9.4	-3.0	-5.9	---
9/10/82	80-L19	16379.0	7892.0	1641.4	353	84.5	---	12.6	-4.1	-4.3	87.7
3/23/81	81-L19	16311.4	7626.4	1653.9	---	—	---	---	---	---	---
9/22/81	81-L19	16317.6	7673.0	1652.1	183	47.0	94.2	7.6	-1.8	-3.5	---
3/23/82	81-L19	16322.0	7711.3	1651.1	182	38.6	77.9	6.5	-1.0	-2.0	85.8
9/10/82	81-L19	16327.6	7754.5	1649.1	171	43.6	93.7	7.4	-1.9	-4.2	---
4/22/83	81-L19	16334.8	7803.5	1647.2	224	49.5	81.1	8.3	-2.0	-3.2	86.3
3/23/82	82-L19	16393.9	7657.6	1650.3	---	---	---	---	---	---	---
9/10/82	82-L19	16397.6	7700.8	1648.6	171	43.4	93.2	85.1	-1.7	-3.6	---
4/22/83	82-L19	16402.8	7751.0	1646.9	224	50.5	82.6	84.1	-1.7	-2.8	87.0
9/09/83	82-L19	16407.9	7786.7	1644.9	140	36.1	94.9	81.9	-2.0	-5.2	---
3/17/84	82-L19	16413.9	7835.0	1642.4	190	48.7	94.1	82.9	-2.5	-4.8	94.1
3/17/84	84-L19	16406.1	7666.7	1648.6	—	—	---	---	—	—	---
8/28/84	84-L19	16409.3	7712.3	1646.4	164	45.8	102.5	4.1	-2.2	-4.9	---
4/05/85	84-L19	16415.3	7765.6	1644.2	220	53.7	89.5	6.4	-2.2	-3.7	94.7
9/05/85	84-L19	16421.2	7807.0	1642.0	153	41.9	100.7	8.1	-2.2	-5.3	---
4/02/86	84-L19	16430.0	7859.2	1639.6	209	52.9	92.9	9.6	-2.4	-4.1	95.9
9/25/86	84-L19	16438.2	7909.5	1636.5	176	51.0	106.4	9.2	-3.2	-6.6	---
4/02/86	86-L19	16402.7	7604.9	1650.1	---	---	---	---	---	---	---
9/25/86	86-L19	16405.8	7653.8	1647.8	176	49.0	102.3	3.6	-2.2	-4.6	---
3/20/87	86-L19	16408.4	7698.2	1646.7	176	44.5	92.7	3.5	-1.2	-2.4	97.2
4/20/88	86-L19	16420.8	7804.6	1642.4	397	107.2	---	6.6	-4.3	-3.9	98.8
4/22/89	86-L19	16436.1	7903.5	1637.0	367	100.2	---	8.8	-5.4	-5.4	99.9

Table 9J. Ice velocity: L-22 km site, Loket Tributary of the Black Rapids Glacier

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Seasonal speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)	Annual speed (m/yr)
3/18/77	77-L23	17447.0	10798.3	1481.0	—	—	—	—	—	—	—
3/21/78	77-L23	17475.0	10882.4	1477.8	368	88.7	—	18.4	-3.1	-3.1	88.2
3/21/78	78-L22	17375.7	10556.9	1495.0	—	—	—	—	—	—	—
3/30/79	78-L22	17395.3	10649.6	1491.4	374	94.8	—	12.0	-3.5	-3.4	92.8
3/28/80	80-L22	17395.1	10452.7	1497.3	—	—	—	—	—	—	—
9/04/80	80-L22	17402.9	10497.1	1495.1	160	45.1	103.6	10.0	-2.1	-4.9	—
3/23/81	80-L22	17410.9	10544.7	1493.7	200	48.4	88.7	9.5	-1.4	-2.6	95.0
6/22/81	80-L22	17416.8	10571.9	1492.9	91	27.8	112.7	12.2	-0.8	-3.4	—
9/22/81	80-L22	17421.8	10596.6	1490.9	92	25.3	101.6	11.5	-2.0	-8.0	—
3/23/81	81-L22	17385.5	10443.5	1498.1	—	—	—	—	—	—	—
6/22/81	81-L22	17390.0	10471.6	1497.3	91	28.4	115.3	9.3	-0.8	-3.3	—
9/22/81	81-L22	17394.5	10497.1	1495.4	92	26.0	104.3	9.9	-1.9	-7.6	—
3/23/82	81-L22	17401.5	10535.7	1494.3	182	39.3	79.2	10.3	-1.1	-2.2	93.9
3/23/82	82-L22	17339.4	10406.5	1498.4	—	—	—	—	—	—	—
9/10/82	82-L22	17345.8	10454.2	1496.5	171	48.1	103.4	7.6	-1.9	-4.1	—
4/22/83	82-L22	17354.8	10504.9	1494.9	224	51.5	84.3	10.0	-1.7	-2.7	92.3
4/22/83	83-L22	17362.7	10440.6	1495.7	—	—	—	—	—	—	—
9/08/83	83-L22	17367.6	10481.4	1493.8	139	41.1	108.7	6.8	-1.9	-5.1	—
3/17/84	83-L22	17375.6	10529.6	1492.5	191	48.8	93.8	9.5	-1.3	-2.5	99.8
8/28/84	83-L22	17384.9	10576.8	1490.5	164	48.1	107.8	11.1	-2.0	-4.5	—
4/05/85	83-L22	17394.7	10633.2	1488.6	220	57.3	95.5	9.9	-1.9	-3.2	100.5
9/11/85	83-L22	17406.0	10679.0	1486.3	159	47.3	109.2	13.8	-2.2	-5.2	—
4/05/85	85-L22	17391.7	10457.3	1495.4	—	—	—	—	—	—	—
9/11/85	85-L22	17399.3	10504.3	1493.3	159	47.7	110.3	9.2	-2.2	-5.0	—
4/02/86	85-L22	17408.7	10555.5	1491.6	203	52.0	94.0	10.5	-1.6	-2.9	100.9
10/07/86	85-L22	17419.5	10612.1	1488.9	188	57.7	112.7	10.8	-2.7	-5.3	—
3/20/87	85-L22	17429.2	10653.4	1486.0	164	42.4	94.9	13.2	-0.9	-2.0	104.1
3/20/87	87-L22	17383.4	10454.1	1498.0	—	—	—	—	—	—	—
4/14/88	87-L22	17403.4	10567.0	1493.2	391	114.8	—	10.0	-4.8	-4.5	107.4
4/22/89	87-L22	17424.8	10672.3	1488.0	373	107.6	—	11.5	-5.2	-5.1	105.6
4/20/90	87-L22	17454.2	10772.9	1480.4	363	105.1	—	16.3	-7.6	-7.6	106.0

Table 10. Additional velocity measurements, Black Rapids Glacier

[Velocity measurements made over periods of time substantially different from the usual spring and fall observation cycle are reported below. Additionally, measurements made at sites other than the 10 index sites are reported below. The coordinates for the base of the stake (X, Y, and Z) are reported in the local coordinate system (see "Coordinate Systems" section). Displacement is the length of the three-dimensional vector representing the net displacement of the base of the stake between the measurement dates. Speed is the speed measured between consecutive observations. Flow azimuth is measured relative to the positive y-axis (north) in the local coordinate system, positive clockwise. Vertical displacement and speed are reported separately. (Vertical displacement is included in the displacement and seasonal speed.) m, meters; m/yr, meters per year; —, no data]

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)
Stakes at index sites surveyed at times of the year other than the usual spring/fall monitoring trips.										
3/22/81	78-8	9052.4	8193.0	1881.7	—	—	—	—	—	—
6/22/81	78-8	9045.1	8217.2	1881.6	92	25.2	101.3	106.9	-0.1	-0.6
9/10/81	78-8	9040.6	8232.2	1881.0	80	15.7	72.4	106.8	-0.6	-2.8
3/22/81	81-8	9082.6	8093.3	1887.0	—	—	—	—	—	—
6/22/81	81-8	9078.2	8107.2	1886.4	92	14.7	58.8	107.7	-0.6	-2.4
9/10/81	81-8	9073.9	8119.6	1885.9	80	13.2	60.8	109.0	-0.5	-2.4
3/22/81	79-14	8862.5	13145.5	1712.5	—	—	—	—	—	—
6/22/81	79-14	8879.2	13150.5	1712.3	92	17.4	69.8	196.4	-0.3	-1.0
9/10/81	79-14	8894.0	13155.1	1711.9	80	15.5	71.4	197.4	-0.3	-1.5
3/23/81	80-20	14818.9	13405.1	1503.8	—	—	—	—	—	—
6/22/81	80-20	14834.0	13405.2	1504.6	91	15.1	61.3	180.4	0.8	3.2
9/10/81	80-20	14845.2	13404.7	1504.4	80	11.2	51.8	177.8	-0.2	-0.9
3/23/81	81-20	14776.7	13400.1	1503.1	—	—	—	—	—	—
6/22/81	81-20	14790.7	13401.1	1503.7	91	14.0	56.9	183.8	0.6	2.2
9/10/81	81-20	14803.5	13399.9	1503.7	80	12.8	59.0	174.8	0.1	0.3
3/24/81	81-26	20640.4	12226.6	1328.2	—	—	—	—	—	—
6/22/81	81-26	20653.4	12224.7	1328.7	90	13.1	53.8	171.6	0.5	2.0
9/22/81	81-26	20665.5	12223.1	1328.9	92	12.2	48.8	172.4	0.2	0.8
3/24/81	80-26	20699.8	12218.0	1331.1	—	—	—	—	—	—
6/22/81	80-26	20712.7	12215.9	1331.6	90	13.1	53.8	170.6	0.5	1.8
3/23/81	80-L22	17410.9	10544.7	1493.7	—	—	—	—	—	—
6/22/81	80-L22	17416.8	10571.9	1492.9	91	27.8	112.7	257.8	-0.8	-3.4
9/22/81	80-L22	17421.8	10596.6	1490.9	92	25.3	101.6	258.5	-2.0	-8.0
3/23/81	81-L22	17385.5	10443.5	1498.1	—	—	—	—	—	—
6/22/81	81-L22	17390.0	10471.6	1497.3	91	28.4	115.3	260.7	-0.8	-3.3
9/22/81	81-L22	17394.5	10497.1	1495.4	92	26.0	104.3	260.1	-1.9	-7.6
4/19/90	UA90-8	9080.8	8063.9	1892.3	—	—	—	—	—	—
7/15/90	UA90-8	9077.5	8077.8	1892.8	87	14.3	60.5	103.5	0.4	1.9
5/04/92	UA90-8	9051.5	8162.6	1887.5	—	—	—	—	—	—
7/02/92	UA90-8	9047.3	8173.6	1887.2	59	11.8	74.0	111.3	-0.4	-2.3
9/23/92	UA90-8	9044.6	8185.4	1886.6	83	12.1	53.9	102.8	-0.6	-2.6
5/25/90	90-14	8782.2	13126.2	1716.1	—	—	—	—	—	—
7/14/90	90-14	8794.6	13129.6	1715.6	50	12.9	96.3	15.2	-0.4	-3.3
5/04/92	92-14	8782.0	13150.5	1717.1	—	—	—	—	—	—
7/02/92	92-14	8796.5	13154.5	1717.4	59	15.1	94.9	15.5	0.3	1.6
9/23/92	92-14	8809.3	13157.8	1715.8	83	13.3	59.4	14.3	-1.6	-7.2

Table 10. Additional velocity measurements, Black Rapids Glacier –continued

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)
Stakes surveyed at locations other than index sites.										
7/22/73	73-6	10203.1	6216.9	1962.8	—	—	—	—	—	—
3/27/74	73-6	10184.9	6241.3	1961.4	248	30.4	44.9	126.7	-1.3	-2.0
7/21/74	73-6	10174.9	6254.5	1960.4	116	16.6	52.7	127.2	-1.0	-3.2
2/28/75	73-6	10159.5	6273.3	1960.2	222	24.4	40.2	129.3	-0.2	-0.3
3/24/76	73-6	10131.9	6311.4	1959.8	390	47.0	44.1	125.9	-0.4	-0.4
2/28/75	75-6	10186.7	6227.5	1961.7	—	—	—	—	—	—
3/24/76	75-6	10159.2	6265.5	1961.2	390	46.9	44.0	125.9	-0.5	-0.5
7/22/73	73-10	8069.0	9669.4	1845.8	—	—	—	—	—	—
7/21/74	73-10	8037.1	9729.6	1842.8	364	68.2	68.5	117.9	-3.0	-3.0
3/01/75	73-10	8021.7	9760.4	1841.0	223	34.4	56.6	116.7	-1.8	-2.9
3/24/76	73-10	7990.4	9819.9	1840.4	389	67.3	63.3	117.7	-0.6	-0.6
7/22/73	73-12	7467.2	11647.1	1769.7	—	—	—	—	—	—
7/21/74	73-12	7477.4	11718.0	1768.0	364	71.6	72.0	81.8	-1.7	-1.7
3/01/75	75-12	7767.7	11446.7	1776.3	—	—	—	—	—	—
3/24/76	75-12	7773.1	11517.5	1774.7	389	71.0	66.8	85.6	-1.6	-1.6
3/19/77	75-12	7771.1	11546.6	1772.4	360	29.5	30.0	- 86.0	-2.3	-2.3
7/22/73	73-16	10770.4	13162.1	1655.8	—	—	—	—	—	—
7/20/74	73-16	10824.3	13168.2	1651.8	363	54.4	54.9	6.5	-4.0	-4.0
2/27/75	73-16	10851.5	13168.8	1650.2	222	27.2	44.9	1.1	-1.7	-2.7
2/27/75	75-16	10776.1	13162.7	1653.7	—	—	—	—	—	—
3/25/76	75-16	10828.4	13166.8	1651.9	392	52.5	49.0	4.5	-1.8	-1.7
7/22/73	73-18	12930.5	13205.1	1591.9	—	—	—	—	—	—
7/20/74	73-18	12983.7	13213.4	1588.0	363	54.0	54.4	9.0	-3.9	-3.9
2/27/75	73-18	13011.0	13218.2	1586.2	222	27.9	46.0	9.9	-1.9	-3.1
2/27/75	75-18	12970.2	13213.4	1588.1	—	—	—	—	—	—
3/25/76	75-18	13020.3	13221.6	1585.6	392	50.8	47.4	9.3	-2.5	-2.3
7/21/73	73-22	16763.7	13188.1	1447.4	—	—	—	—	—	—
7/21/74	74-22	16791.9	13181.5	1445.6	365	29.0	29.1	- 13.2	-1.8	-1.8
3/02/75	74-22	16807.4	13176.5	1444.8	224	16.3	26.7	- 17.9	-0.9	-1.5
3/02/75	75-22	16763.1	13173.8	1446.1	—	—	—	—	—	—
3/24/76	75-22	16789.4	13172.1	1445.5	388	26.4	24.9	- 3.7	-0.6	-0.6
7/21/73	73-28	22458.6	11874.0	1278.9	—	—	—	—	—	—
7/20/74	73-28	22493.7	11863.4	1276.2	364	36.7	36.9	- 16.9	-2.8	-2.8
3/03/75	75-28	22659.0	11584.5	1267.1	—	—	—	—	—	—
3/25/76	75-28	22689.6	11574.9	1265.4	388	32.1	30.3	- 17.5	-1.7	-1.6
7/21/73	73-30	24710.5	11171.8	1204.2	—	—	—	—	—	—
7/20/74	73-30	24736.9	11170.0	1202.2	364	26.5	26.6	- 3.8	-1.9	-1.9
3/04/75	73-30	24747.6	11170.9	1201.3	227	10.8	17.5	4.4	-1.0	-1.6
3/04/75	75-30	24720.8	11177.1	1202.1	—	—	—	—	—	—
3/26/76	75-30	24745.6	11176.3	1199.8	388	24.9	23.5	- 1.7	-2.3	-2.2
7/22/73	73-34	28853.0	10473.7	1083.0	—	—	—	—	—	—
7/20/74	73-34	28866.0	10475.1	1081.1	363	13.2	13.3	6.1	-1.8	-1.8
3/04/75	75-34	28840.1	10485.8	1079.3	—	—	—	—	—	—
3/26/76	75-34	28854.6	10487.0	1076.8	388	14.8	14.0	4.7	-2.5	-2.4
7/21/73	73-36	30596.8	10265.9	1035.7	—	—	—	—	—	—
7/20/74	73-36	30606.9	10270.1	1034.4	364	11.0	11.1	22.4	-1.3	-1.3
3/06/75	73-36	30613.7	10268.9	1033.22	229	6.9	11.1	- 9.4	-1.2	-1.9
3/06/75	75-36	30552.6	10267.4	1033.15	—	—	—	—	—	—
2/26/76	75-36	30562.3	10268.1	1031.9	357	9.8	10.0	4.2	-1.3	-1.3

Table 11. Longitudinal velocity profile, Black Rapids Glacier, July 1973 to July 1974

[Speeds are plotted in figure 7. The coordinates for the base of the stake (X, Y, and Z) are reported in the local coordinate system (see "Coordinate Systems" section). Displacement is the length of the three-dimensional vector representing the net displacement of the base of the stake between the measurement dates. Speed is the speed measured between consecutive observations. Flow azimuth is measured relative to the positive y-axis (north) in the local coordinate system, positive clockwise. Vertical displacement and speed are reported separately. (Vertical displacement is included in the displacement and seasonal speed.) m, meters; m/yr, meters per year; ---, no data]

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)
7/24/73	73-4	11352.5	4779.4	2024.2						
7/22/74	73-4	11311.3	4837.1	2014.3	363	71.5	72.1	324.5	-10.0	-10.0
7/22/73	73-6	10203.1	6216.9	1962.8						
7/21/74	73-6	10174.9	6254.5	1960.4	364	47.0	47.3	323.1	-2.3	-2.4
7/15/73	73-8	9126.7	7794.5	1895.1						
7/22/74	73-8	9111.9	7845.1	1893.7	372	52.7	51.8	343.7	-1.4	-1.4
7/22/73	73-10	8069.0	9669.4	1845.8						
7/21/74	73-10	8037.1	9729.6	1842.8	364	68.2	68.5	332.1	-3.0	-3.0
7/22/73	73-12	7467.2	11647.1	1769.7						
7/21/74	73-12	7477.4	11718.0	1768.0	364	71.6	72.0	8.2	-1.7	-1.7
7/23/73	73-14	8933.8	13150.6	1710.7						
7/12/74	73-14	8989.3	13166.4	1709.5	354	57.7	59.6	74.1	-1.2	-1.2
7/22/73	73-16	10770.4	13162.1	1655.8						
7/20/74	73-16	10824.3	13168.2	1651.8	363	54.4	54.9	83.5	-4.0	-4.0
7/22/73	73-18	12930.5	13205.1	1591.9						
7/20/74	73-18	12983.7	13213.4	1588.0	363	54.0	54.4	81.0	-3.9	-3.9
7/21/73	73-20	14823.1	13405.3	1510.6						
7/21/74	73-20	14871.2	13404.0	1511.9	365	48.1	48.3	91.5	1.3	1.3
7/21/73	73-22	16763.7	13188.1	1447.4						
7/21/74	74-22	16791.9	13181.5	1445.6	365	29.0	29.1	103.2	-1.8	-1.8
7/21/73	73-26	20597.9	12233.3	1347.8						
7/21/74	74-26	20644.3	12226.6	1345.7	365	46.9	47.0	98.2	-2.1	-2.1
7/21/73	73-28	22458.6	11874.0	1278.9						
7/20/74	73-28	22493.7	11863.4	1276.2	364	36.7	36.9	106.9	-2.8	-2.8
7/21/73	73-30	24710.5	11171.8	1204.2						
7/20/74	73-30	24736.9	11170.0	1202.2	364	26.5	26.6	93.8	-1.9	-1.9
7/23/73	73-32-B	26418.5	10879.7	1141.2						
3/31/74	73-32-B	26427.4	10877.7	1141.3	251	9.2	13.4	102.7	0.2	0.2
3/31/74	74-32-B	26427.4	10877.7	1138.3						
7/21/74	74-32-B	26433.4	10876.5	1140.4	112	6.4	21.2	101.1	2.1	6.9
7/22/73	73-34	28853.0	10473.7	1083.0						
7/20/74	73-34	28866.0	10475.1	1081.1	363	13.2	13.3	83.9	-1.8	-1.8
7/21/73	73-36	30596.8	10265.9	1035.7						
7/20/74	73-36	30606.9	10270.1	1034.4	364	11.0	11.1	67.6	-1.3	-1.3

Table 12. Velocity cross-profiles, Black Rapids Glacier

[Velocity measurements across the width of the glacier are reported below. Velocities are plotted in figure 8. The coordinates (X, Y, and Z) are reported in the local coordinate system (see "Coordinate Systems" section). Displacement is the length of the three-dimensional vector representing the motion of the base of the stake between the measurement dates. Flow azimuth is measured relative to the positive x-axis in the local coordinate system. Vertical displacement and speed are reported separately. (They are included in the displacement and seasonal speed.) See the note attached to each profile for special considerations. m, meters; m/yr, meters per year]

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)
Willsear (15 km) velocity cross-profile										
Note: The markers for this profile were surface riding tetrahedrons. Only the horizontal velocities are reported for this site.										
5/23/90	S5	9458.5	12217.6							
7/14/90		9467.6	12220.0		52	9.3	66.8	14.8		
5/23/90	S3	9471.8	12753.8							
7/14/90		9484.3	12755.8		52	12.6	90.3	8.9		
5/23/90	S2	9488.3	13026.9							
7/14/90		9501.4	13028.7		52	13.3	95.0	7.8		
5/23/90	S1	9504.2	13284.4							
7/14/90		9517.7	13286.2		52	13.6	97.4	7.5		
5/23/90	WE	9531.4	13584.8							
7/14/90		9543.1	13586.2		52	11.8	84.3	6.8		
5/23/90	N1	9532.6	13820.8							
7/14/90		9540.1	13821.8		52	7.6	54.6	7.5		
5/23/90	N2	9535.0	13996.7							
7/14/90		9538.7	13997.3		52	3.7	26.7	9.0		
5/23/90	N3	9535.9	14164.4							
7/14/90		9536.7	14164.8		52	0.9	6.3	24.0		
20 km velocity cross-profile										
Note: The markers for this profile were stakes drilled into the ice. The tops were surveyed, and the velocity for the top of the stake is reported with no corrections made for stake lean.										
4/24/87	N3	14910.9	14118.0	1521.4						
4/17/88		14956.7	14117.3	1521.8	359	45.8	46.7	-0.9	0.4	0.4
4/24/87	N2	14896.2	13780.1	1511.4						
4/17/88		14951.0	13779.4	1509.9	359	54.8	55.8	-0.8	-1.5	-1.5
4/24/87	N1	14874.2	13608.8	1511.9						
4/17/88		14931.1	13608.6	1512.5	359	56.8	57.9	-0.2	0.7	0.7
4/24/87	86-20	14883.8	13401.4	1511.8						
4/17/88		14938.7	13400.4	1513.8	359	55.0	56.1	-1.1	2.0	2.0
4/24/87	S1	14866.3	13130.8	1517.7						
4/17/88		14923.4	13130.3	1518.9	359	57.2	58.3	-0.5	1.2	1.2
4/24/87	S2	14862.1	12925.6	1516.9						
4/17/88		14909.4	12923.6	1518.3	359	47.3	48.2	-2.5	1.3	1.4
4/24/87	S3	14853.9	12769.0	1514.7						
4/17/88		14893.8	12766.2	1518.1	359	40.1	40.8	-4.1	3.4	3.5

Table 12. Velocity cross-profiles: Black Rapids Glacier, --continued

Date	Stake	Coordinate X	Coordinate Y	Coordinate Z	Period (days)	Displacement (m)	Speed (m/yr)	Flow azimuth (degrees)	Vertical displacement (m)	Vertical speed (m/yr)
24.0 km velocity cross-profile										
Note: The markers for this profile were stakes drilled into the ice. The tops were surveyed, and the velocity for the top of the stake is reported with no corrections made for stake lean.										
3/03/75	75-24.0-1	18712.2	13419.7	1402.7						
3/25/76		18721.7	13419.5	1401.0	388	9.7	9.1	-1.2	-1.8	-1.7
3/03/75	75-24.0-2	18638.9	13128.8	1400.6						
3/25/76		18654.3	13128.5	1400.0	388	15.4	14.5	-1.2	-0.6	-0.5
3/03/75	75-24.0-3	18556.6	12918.6	1403.5						
3/25/76		18575.3	12919.0	1402.4	388	18.7	17.6	1.1	-1.1	-1.1
3/03/75	75-24.0-4	18390.0	12449.7	1407.2						
3/25/76		18430.3	12465.1	1406.1	388	43.2	40.7	21.0	-1.2	-1.1
3/03/75	75-24.0-5	18131.8	11779.1	1441.3						
3/25/76		18184.1	11819.6	1437.2	388	66.3	62.5	37.8	-4.1	-3.9
3/03/75	75-24.0-6	17896.4	11166.7	1460.8						
3/25/76		17945.0	11219.4	1457.8	388	71.8	67.7	47.4	-3.0	-2.8
32 km velocity cross-profile										
Note: The markers for this profile were stakes drilled into the ice. The tops were surveyed, and the velocity for the top of the stake is reported with no corrections made for stake lean.										
7/22/73	73-32.0-1	26487.3	11663.3	1162.2						
7/20/74		26495.1	11660.1	1160.2	363	8.6	8.7	-22.3	-2.0	-2.0
7/22/73	73-32.0-2	26432.8	11181.5	1163.5						
7/20/74		26448.2	11177.6	1161.9	363	15.9	16.1	-14.0	-1.5	-1.6
7/22/73	73-32.0	26392.5	10869.0	1146.2						
7/20/74		26409.3	10864.7	1143.8	363	17.5	17.6	-14.2	-2.3	-2.3
7/22/73	73-32.0-4	26311.6	10378.3	1148.9						
7/20/74		26325.0	10375.4	1145.9	363	14.0	14.1	-12.0	-3.0	-3.1
7/22/73	73-32.0-5	26259.6	10023.2	1171.0						
7/20/74		26264.3	10024.0	1167.2	363	6.1	6.2	9.0	-3.8	-3.8

Table 13. Range-line speed measurements, Black Rapids Glacier

[In the early days of the Black Rapids Glacier project, ice velocities were measured by visually lining up pairs of markers fixed to the rock adjacent to the glacier. (See "Range-Line Speed Measurements" section in the text for the full description of techniques.) The locations of these "range-line" motion observation sites are indicated stake name. For example, stake 73-8 was near the 8 km site. Period is the number of days between observations. Displacement is the distance the marker moved between observations. Speed is calculated over the period of observation. Abbreviations: m, meters; m/yr, meters per year]

Date	Stake	Period (days)	Displace-ment (m)	Speed (m/yr)
10/27/73	73-8	installed	—	—
3/30/74	73-8	154	22.6	53.9
7/22/74	72-8/74-8	114	10.6	34.2
2/28/75	74-8	221	31.5	52.3
7/25/73	73-14	installed	—	—
10/25/73	73-14	92	13.6	54.5
3/30/74	73-14	156	18.6	43.8
7/21/74	73-14	113	22.6	73.7
8/18/71	72-19	installed	—	—
8/03/72	72-19/73-19	351	59.5	62.1
10/19/72	73-19	77	9.0	43.2
4/02/73	73-19	165	19.4	43.2
5/22/73	73-19	50	6.7	49.9
7/19/73	73-19	58	17.5	112.1
8/18/71	72-26	installed	—	—
8/03/72	72-26/73-26	351	44.3	46.2
10/19/72	73-26	77	9.6	46.1
4/02/73	73-26	165	14.2	31.6
5/22/73	73-26	50	3.9	29.1
7/24/73	73-26	63	12.5	73.6
10/25/73	73-26-b	installed	—	—
3/29/74	73-26-b	155	17.2	40.8
8/18/71	71-32	installed	—	—
8/03/72	71-32/72-32	351	13.6	14.2
10/19/72	72-32	77	3.2	15.4
5/22/73	72-32	215	5.4	9.2
7/22/73	72-32/73-32	61	5.0	30.4
10/25/73	73-32	95	4.3	16.7
3/31/74	73-32	157	4.6	10.8
7/30/73	73-38.0	installed	—	—
10/25/73	73-38.0	87	4.2	17.8
3/31/74	73-38.0	157	3.1	7.3
7/21/74	73-38.0	112	11.7	38.5
3/31/74	73-38.8	installed	—	—
7/21/74	73-38.8	112	10.4	34.2

Table 14A. Surface altitude: 2 km site, Black Rapids Glacier

[Surface altitudes are plotted in figure 3A. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.)]

Date	Surface altitude (meters)	Snow depth (meters)
3/18/77	2229.6	6.00
9/23/77	2225.9	1.49
3/22/78	2227.1	4.39
9/4/80	2225.7	0.63
3/22/81	2227.5	3.67
9/10/81	2227.4	1.25
3/24/82	2228.7	no data
9/10/82	2227.1	no data
3/16/84	2228.7	no data
8/28/84	2226.9	no data
4/4/85	2229.0	no data

Table 14B. Surface altitude: 4 km site, Black Rapids Glacier

[Surface altitudes are plotted in figure 3B. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.) —, no data]

Date	Surface altitude (meters)	Snow depth (meters)
7/24/73	2019.1	—
3/27/74	2018.9	1.93
7/22/74	2017.2	0.79
2/27/75	2019.3	3.76
8/28/75	2017.0	0.02
3/24/76	2020.3	3.95
9/13/76	2017.9	0.35
3/18/77	2022.4	5.38
9/23/77	2020.8	1.16
3/18/78	2023.1	3.41
7/28/78	2019.9	2.17
10/23/78	2022.9	1.50
3/28/79	2022.8	3.65
8/23/79	2018.8	0.01
3/27/80	2024.5	4.99
9/4/80	2020.9	0.45
3/22/81	2023.3	3.36
9/10/81	2022.2	0.50
3/24/82	2024.6	3.56
9/10/82	2022.1	0.40
4/23/83	2023.8	3.88
9/18/83	2022.1	0.40
3/16/84	2023.8	3.10
8/28/84	2021.0	0.42
4/4/85	2022.9	3.80
9/12/85	2020.8	0.72
4/3/86	2023.1	3.80
9/25/86	2021.3	0.45
3/18/87	2023.8	4.26

Table 14C. Surface altitude: 8 km site, Black Rapids Glacier

[Surface altitudes are plotted in figure 3C. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.) g/cm³, grams per cubic centimeter]

Date	Surface altitude (meters)	Snow depth (meters)	Snow density (g/cm³)
3/27/74	1889.4	1.40	0.36
7/22/74	1888.4	0.35	0.51
2/28/75	1889.5	2.45	0.33
8/28/75	1887.5	0.78	0.51
3/24/76	1890.3	2.85	0.33
9/13/76	1888.1	0.25	0.26
3/18/77	1891.5	3.87	0.40
9/23/77	1889.8	0.77	0.28
3/22/78	1890.7	2.28	0.36
10/23/78	1889.4	1.12	0.26
3/28/79	1892.0	2.57	0.36
8/23/79	1889.1	0.26	0.26
3/27/80	1891.6	3.11	0.36
9/04/80	1890.0	0.32	0.26
3/22/81	1892.4	2.67	0.36
6/22/81	1891.3	1.86	0.40
9/10/81	1891.1	0.55	0.26
3/24/82	1893.5	2.70	0.36
9/10/82	1891.1	0.25	0.26
4/21/83	1893.6	2.30	0.36
9/08/83	1891.7	0.61	0.26
3/17/84	1893.9	3.07	0.36
8/28/84	1892.0	0.81	0.26
4/04/85	1894.5	2.74	0.36
9/11/85	1893.1	0.40	0.26
4/03/86	1895.1	2.25	0.36
9/25/86	1893.3	0.38	0.26
3/18/87	1895.8	3.00	0.44
8/27/87	1893.4	1.31	0.51
4/19/90	1896.9	4.40	0.36
5/01/91	1896.2	2.99	0.36
5/04/92	1897.1	3.27	0.36
9/23/92	1895.0	0.49	0.26

Table 14D. Surface altitude: 14 km site, Black Rapids Glacier

[Ice equivalent altitudes are plotted in figure 3D. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.) Ice equivalent altitude is calculated by converting the snow depth to its equivalent ice thickness and adding this number to the ice surface altitude. g/cm³, grams per cubic centimeter; m, meters; —, not applicable]

Date	Surface altitude (meters)	Snow depth (meters)	Snow density (g/cm³)	Ice equivalent altitude (m)
7/23/73	1718.3	0.00	---	1718.3
3/30/74	1718.9	1.49	0.34	1718.0
7/21/74	1717.5	0.00	---	1717.5
3/01/75	1718.6	2.26	0.34	1717.1
8/26/75	1716.1	0.02	0.20	1716.1
3/24/76	1718.9	2.23	0.34	1717.5
9/13/76	1716.3	0.27	0.20	1716.1
3/18/77	1719.8	3.09	0.34	1717.9
9/23/77	1717.4	0.66	0.20	1716.9
3/18/78	1719.4	2.34	0.34	1718.0
9/24/78	1716.1	0.17	0.20	1716.0
3/28/79	1718.8	2.09	0.33	1717.5
8/23/79	1715.0	0.00	---	1715.0
3/27/80	1718.6	2.90	0.33	1716.8
9/04/80	1716.3	0.08	0.20	1716.2
3/22/81	1718.9	2.22	0.33	1717.5
6/22/81	1718.1	1.14	0.40	1717.4
9/10/81	1717.1	0.30	0.20	1716.9
3/25/82	1719.9	2.06	0.32	1718.6
9/10/82	1718.0	0.11	0.20	1717.9
4/21/83	1720.5	2.29	0.36	1719.1
9/08/83	1718.0	0.46	0.20	1717.7
3/16/84	1720.7	2.43	0.36	1719.2
8/28/84	1717.9	0.16	0.20	1717.7
4/05/85	1720.9	2.38	0.36	1719.4
9/05/85	1718.8	0.08	0.20	1718.7
4/04/86	1721.7	2.09	0.37	1720.5
9/25/86	1719.8	0.37	0.20	1719.5
3/20/87	1722.7	2.63	0.37	1721.1
8/27/87	1719.8	0.00	---	1719.8
4/21/88	1723.2	2.54	0.37	1721.7
4/15/89	1722.6	1.95	0.37	1721.5
5/23/90	1722.8	2.70	0.37	1721.2
5/01/91	1721.7	2.45	0.37	1720.3
5/04/92	1722.3	2.72	0.37	1720.7
9/23/92	1719.2	0.55	0.37	1718.9

Table 14E. Surface altitude: 20 km site, Black Rapids Glacier

[Ice equivalent altitudes are plotted in figure 3E. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.) Ice equivalent altitude is calculated by converting the snow depth to its equivalent ice thickness and adding this number to the ice surface altitude. g/cm³; grams per cubic centimeter; m, meters; ---, not applicable]

Date	Surface altitude (meters)	Snow depth (meters)	Snow density (g/cm³)	Ice equivalent altitude (m)
7/21/73	1514.1	0.00	---	1514.1
7/21/74	1513.2	0.00	---	1513.2
3/02/75	1513.6	1.45	0.32	1512.6
8/25/75	1510.5	0.00	---	1510.5
3/25/76	1512.8	1.28	0.32	1512.0
9/13/76	1509.7	0.25	0.20	1509.5
3/19/77	1512.4	2.23	0.32	1510.9
9/21/77	1509.6	0.16	0.20	1509.5
3/18/78	1511.9	1.56	0.32	1510.9
9/23/78	1508.0	0.15	0.20	1507.9
3/29/79	1510.2	1.43	0.32	1509.3
3/26/80	1510.1	2.27	0.32	1508.6
9/04/80	1507.0	0.07	0.20	1507.0
3/23/81	1509.6	1.55	0.32	1508.6
6/22/81	1509.3	0.00	---	1509.3
9/10/81	1507.3	0.01	0.20	1507.3
3/25/82	1509.4	1.40	0.32	1508.5
9/10/82	1506.7	0.00	---	1506.7
4/21/83	1510.2	1.77	0.32	1509.0
9/08/83	1506.9	0.14	0.20	1506.8
3/19/84	1510.1	1.57	0.32	1509.1
8/28/84	1507.8	0.00	---	1507.8
4/05/85	1511.4	1.67	0.32	1510.3
9/11/85	1509.7	0.03	0.20	1509.6
4/02/86	1513.6	1.72	0.32	1512.5
9/25/86	1510.8	0.27	0.20	1510.6
3/18/87	1514.6	1.92	0.32	1513.4
8/27/87	1512.2	0.00	---	1512.2
4/16/88	1515.3	2.37	0.32	1513.8
4/15/89	1515.4	1.50	0.32	1514.4
5/26/90	1515.2	1.80	0.32	1514.0
5/01/91	1513.2	1.50	0.32	1512.3
5/05/92	1514.0	2.06	0.32	1512.7
9/23/92	1510.8	0.37	0.20	1510.5

Table 14F. Surface altitude: 26 km site, Black Rapids Glacier

[Ice equivalent altitudes are plotted in figure 3F. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.) Ice equivalent altitude is calculated by converting the snow depth to its equivalent ice thickness and adding this number to the ice surface altitude. g/cm³, grams per cubic centimeter; m, meters; ---, not applicable]

Date	Surface altitude (meters)	Snow depth (meters)	Snow density (g/cm³)	Ice equivalent altitude (m)
7/21/73	1343.5	0.00	---	1343.5
7/21/74	1342.7	0.00	---	1342.7
3/3/75	1343.0	1.59	0.31	1342.0
3/26/76	1342.6	1.81	0.31	1341.4
9/13/76	1338.5	0.00	---	1338.5
3/16/77	1341.9	2.17	0.31	1340.5
9/20/77	1337.9	0.02	0.20	1337.8
3/19/78	1340.9	1.71	0.31	1339.8
9/23/78	1336.3	0.12	0.20	1336.2
3/28/79	1339.3	1.43	0.31	1338.4
8/23/79	1334.7	0.00	---	1334.7
3/26/80	1337.1	1.87	0.31	1335.8
9/4/80	1332.6	0.00	---	1332.6
3/24/81	1334.8	1.13	0.31	1334.1
6/22/81	1333.4	0.00	---	1333.4
9/22/81	1330.4	0.07	0.20	1330.4
3/22/82	1332.3	1.35	0.31	1331.4
9/10/82	1328.0	0.00	---	1328.0
4/20/83	1331.3	1.80	0.31	1330.1
9/8/83	1327.5	0.09	0.20	1327.4
3/19/84	1330.4	1.41	0.31	1329.4
8/28/84	1326.5	0.00	---	1326.5
4/5/85	1329.0	1.34	0.31	1328.2
9/5/85	1325.0	0.03	0.20	1325.0
4/9/86	1326.7	1.08	0.31	1326.0
10/7/86	1322.1	0.24	0.20	1321.9
3/19/87	1322.8	1.54	0.21	1321.6

Table 14G. Surface altitude: 32 km site, Black Rapids Glacier

[Ice equivalent altitudes are plotted in figure 3G. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.) Ice equivalent altitude is calculated by converting the snow depth to its equivalent ice thickness and adding this number to the ice surface altitude. g/cm³; grams per cubic centimeter; m, meters; —, not applicable]

Date	Surface altitude (meters)	Snow depth (meters)	Snow density (g/cm³)	Ice equivalent altitude (m)
7/23/73	1142.1	0.00	---	1142.1
3/31/74	1140.9	0.68	0.35	1140.5
7/21/74	1139.4	0.00	---	1139.4
3/4/75	1138.9	1.20	0.35	1138.2
8/25/75	1134.8	0.00	---	1134.8
3/26/76	1137.3	1.42	0.27	1136.3
9/13/76	1131.2	0.00	---	1131.2
3/14/77	1134.5	2.05	0.35	1133.2
9/20/77	1128.3	0.00	---	1128.3
3/23/78	1131.5	1.46	0.35	1130.6
9/22/78	1125.2	0.13	0.20	1125.1
3/29/79	1127.6	1.22	0.35	1126.8
3/29/80	1124.8	1.94	0.35	1123.6
9/4/80	1119.7	0.00	---	1119.7
3/24/81	1122.2	1.27	0.35	1121.4
9/14/81	1117.1	0.00	---	1117.1
3/22/82	1119.6	1.01	0.35	1118.9
9/11/82	1114.5	0.00	---	1114.5
4/20/83	1117.7	1.63	0.32	1116.6
9/8/83	1112.7	0.00	---	1112.7
3/18/84	1115.1	1.34	0.36	1114.3
8/28/84	1109.7	0.00	---	1109.7
4/5/85	1112.7	1.34	0.35	1111.8
9/5/85	1109.1	0.00	---	1109.1
4/9/86	1111.5	1.66	0.35	1110.5
10/7/86	1107.6	0.00	---	1107.6
3/19/87	1109.6	1.63	0.43	1108.8
8/27/87	1104.9	0.00	---	1104.9

Table 14H. Surface altitude: 38 km site, Black Rapids Glacier

[Ice equivalent altitudes are plotted in figure 3H. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.) Ice equivalent altitude is calculated by converting the snow depth to its equivalent ice thickness and adding this number to the ice surface altitude. g/cm³; grams per cubic centimeter; m, meters; ---, not applicable]

Date	Surface altitude (meters)	Snow depth (meters)	Snow density (g/cm³)	Ice equivalent altitude (m)
7/30/73	958.8	0.00	---	958.8
3/31/74	956.5	0.51	0.36	956.2
7/21/74	953.3	0.00	---	953.3
3/6/75	952.8	0.94	0.36	952.3
8/26/75	948.4	0.00	---	948.4
3/26/76	948.7	0.80	0.36	948.2
9/13/76	942.7	0.00	---	942.7
3/14/77	943.5	0.70	0.36	943.0
9/20/77	936.5	0.00	---	936.5
3/20/78	939.0	1.19	0.36	938.3
9/23/78	932.5	0.08	0.20	932.4
3/29/79	932.3	0.30	0.36	932.1
8/23/79	926.4	0.00	---	926.4
3/29/80	926.6	0.21	0.36	926.5
9/4/80	921.0	0.00	---	921.0
3/24/81	921.8	0.13	0.36	921.7
9/14/81	915.7	0.00	---	915.7
3/22/82	916.8	0.12	0.36	916.7
9/11/82	911.1	0.00	---	911.1
4/20/83	912.9	0.49	0.36	912.6
9/8/83	907.4	0.00	---	907.4
3/18/84	908.6	0.24	0.36	908.5
8/29/84	903.4	0.00	---	903.4
9/5/85	900.1	0.00	---	900.1
4/6/86	901.2	0.45	0.36	900.9
3/19/87	895.9	0.03	0.36	895.9

Table 14I. Surface altitude: L-19 km site, Loket Tributary of the Black Rapids Glacier

[Surface altitudes are plotted in figure 3I. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.) g/cm³; grams per cubic centimeter; m, meters; ---, not applicable]

Date	Surface altitude (meters)	Snow depth (meters)	Snow density (g/cm³)
3/28/80	1654.8	3.65	0.35
9/04/80	1652.1	0.22	0.50
3/23/81	1654.7	2.64	0.35
9/22/81	1652.3	0.52	0.20
3/23/82	1654.4	2.38	0.35
9/10/82	1651.4	0.15	0.20
4/22/83	1654.0	2.84	0.35
9/09/83	1650.7	0.00	---
3/17/84	1653.2	2.74	0.35
8/28/84	1649.8	0.04	0.20
4/05/85	1652.7	2.77	0.35
9/05/85	1650.3	0.15	0.80
4/02/86	1652.9	2.28	0.35
9/25/86	1649.2	0.30	0.20
3/20/87	1652.7	3.21	0.44
4/20/88	1653.2	3.19	0.35
4/22/89	1652.0	no data	no data

Table 14J. Surface altitude: L-22 km site, Loket Tributary of the Black Rapids Glacier

[Ice equivalent altitudes are plotted in figure 3J. Surface altitude is the computed altitude of the index site, which has a fixed horizontal position. (See "Monitoring of Index Site Altitudes" section in text.) Ice equivalent altitude is calculated by converting the snow depth to its equivalent ice thickness and adding this number to the ice surface altitude g/cm³, grams per cubic centimeter; m, meters; —, not applicable]

Date	Surface altitude (meters)	Snow depth (meters)	Snow density (g/cm³)	Ice equivalent altitude (m)
3/21/78	1503.3	2.07	0.32	1502.0
3/30/79	1501.4	1.97	0.32	1500.1
3/28/80	1500.3	2.66	0.32	1498.6
9/04/80	1496.6	0.07	0.20	1496.5
3/23/81	1499.8	1.80	0.32	1498.6
9/22/81	1496.7	0.40	0.20	1496.4
3/23/82	1499.3	1.56	0.32	1498.3
9/10/82	1495.7	0.00	---	1495.7
4/22/83	1499.1	1.98	0.32	1497.8
9/08/83	1495.7	0.21	0.20	1495.5
3/17/84	1498.9	1.97	0.32	1497.6
8/28/84	1496.1	0.00	—	1496.1
4/05/85	1499.3	1.96	0.32	1498.0
9/11/85	1496.4	0.00	---	1496.4
4/02/86	1499.6	1.72	0.32	1498.5
10/07/86	1496.7	0.36	0.20	1496.4
3/20/87	1500.0	2.38	0.32	1498.4
8/27/87	1496.8	0.00	—	1496.8
4/14/88	1499.9	1.93	0.32	1498.7
4/22/89	1498.5	1.84	0.32	1497.3

Table 15. Extensive glacier surface altitude surveys of 1973 and 1976, Black Rapids Glacier

[See figure 9 for target locations]

Date	Target	Coordinate X	Coordinate Y	Coordinate Z
7/21/73	G1	21235.6	11065.2	1304.2
7/21/73	G2	21253.4	11123.6	1306.2
7/21/73	G3	21268.1	11172.3	1305.1
7/21/73	G4	21301.6	11280.9	1323.1
7/21/73	G5	21326.9	11364.1	1306.1
7/21/73	G6	21348.9	11436.4	1310.5
7/21/73	G7	21376.7	11527.5	1307.4
7/21/73	G8	21404.7	11620.6	1310.9
7/21/73	G9	21432.6	11711.1	1310.3
7/21/73	73-26.0	20597.9	12233.3	1347.8
7/21/73	G10	21461.2	11804.4	1310.9
7/21/73	G11	21497.2	11923.4	1312.8
7/21/73	G12	21531.3	12033.8	1318.3
7/21/73	73-28.0	22458.6	11874.0	1278.9
7/21/73	G13	21573.3	12170.6	1312.2
7/21/73	G14	21606.3	12281.0	1312.3
7/21/73	G15	21635.2	12375.8	1310.8
7/21/73	G16	21659.7	12455.5	1313.1
7/21/73	G17	21690.9	12560.0	1319.6
7/21/73	G18	21715.9	12643.9	1313.7
7/21/73	73-30.0	24710.5	11171.8	1204.1
7/21/73	G19	21744.5	12733.5	1307.0
7/21/73	G20	21770.1	12817.2	1317.7
7/21/73	G21	21797.4	12910.0	1313.7
7/21/73	G22	21837.1	13039.4	1318.9
7/21/73	G23	21848.8	13151.7	1303.7
7/21/73	G24-RMD1	21934.8	13357.5	1371.7
7/21/73	RMD2	22020.6	13453.0	1397.0
7/22/73	73-32.0-2	26432.8	11181.5	1163.5
7/22/73	73-32.0	26392.5	10869.0	1146.2
7/22/73	73-34.0	28853.0	10473.7	1083.0
7/22/73	73-32.OTC	26405.5	10865.2	1146.1
7/22/73	73-32.0-1	26487.3	11663.3	1162.2
7/22/73	73-32.0-4	26311.6	10378.3	1148.9
7/22/73	73-32.0-5	26259.6	10023.2	1171.0
7/22/73	73-22.0	16763.7	13188.1	1447.4
7/20/73	L1	18499.3	12590.4	1416.6
7/22/73	73-18.0	12930.5	13205.1	1591.9
7/20/73	L2	17208.8	9666.6	1554.6
7/22/73	73-20.0	14808.5	13392.1	1516.6
7/20/73	L3	17284.6	9851.4	1540.2
7/20/73	L4	17360.3	10033.7	1532.6
7/20/73	L5	17424.4	10185.8	1528.0
7/20/73	L6	17497.1	10369.0	1519.5
7/20/73	L7	17573.0	10550.1	1508.6
7/20/73	L8	17651.9	10739.0	1493.7
7/20/73	L9	17729.7	10928.1	1479.4
7/20/73	L10	17806.8	11116.4	1468.9
7/20/73	L11	17884.9	11304.1	1462.8
7/20/73	L12	17961.2	11487.5	1457.9
7/20/73	L13	18038.9	11673.9	1451.0
7/20/73	L14	18116.0	11864.6	1440.4
7/20/73	L15	18191.1	12048.5	1428.8
7/20/73	L16	18266.3	12229.2	1417.4
7/20/73	L17	18336.7	12394.9	1411.3
7/20/73	L18	18372.8	12483.5	1409.7
7/20/73	L19	18410.5	12573.0	1414.9
7/20/73	L20	18436.2	12636.3	1403.0
7/20/73	L21	18477.1	12735.9	1404.8
7/20/73	L22	18549.7	12911.3	1404.5
7/20/73	L23	18619.6	13081.1	1403.2
7/20/73	L24	18693.6	13261.4	1402.8
7/20/73	L25	18751.0	13401.0	1400.5
7/20/73	L26	18792.6	13500.9	1410.3
7/20/73	L27	18836.8	13610.0	1404.5
7/20/73	L28	18909.4	13786.0	1386.9
7/20/73	L29	18962.6	13910.8	1391.9
7/22/73	G25	14564.8	12523.9	1531.3
7/22/73	G26	4568.6	12536.9	1524.4
7/22/73	G27	14564.1	12642.9	1526.9
7/22/73	G28	14563.9	12691.4	1521.8
7/22/73	G29	14562.5	12778.8	1522.7
7/22/73	G30	14561.9	12882.1	1519.9
7/22/73	G31	14560.5	13005.3	1515.8
7/22/73	G32	14559.7	13105.4	1521.3
7/22/73	G33	14558.8	13206.6	1518.9
7/22/73	G34	14558.6	13283.6	1518.6
7/22/73	G35	14557.6	13379.0	1521.9
7/22/73	G36	14556.7	13481.3	1522.1
7/22/73	G37	14555.8	13585.2	1521.1
7/22/73	G38	14555.3	13686.6	1520.2
7/22/73	G39	14553.8	13786.2	1518.2
7/22/73	G40	14552.6	13885.7	1524.0
7/22/73	G41	14552.2	13977.0	1527.0
7/22/73	G42	14551.5	14065.2	1524.4
7/22/73	G43	14550.2	14162.4	1529.2
7/22/73	G44	14549.6	14239.5	1532.3
7/22/73	G45	14561.7	14319.0	1528.3
7/22/73	G46	14551.0	14357.1	1523.2
7/22/73	G47	14549.6	14391.6	1520.0
7/22/73	G48	14549.0	14454.9	1523.4
7/22/73	G49	14547.8	14490.1	1517.4
7/22/73	73-16.0	10770.4	13162.1	1655.8
7/22/73	73-14.0	8925.0	13137.7	1716.7
7/22/73	73-36.0	30596.8	10265.9	1035.7
7/22/73	73-40.0	34223.9	12458.6	876.3
7/22/73	73-4.0	11341.3	4774.7	2029.0
7/22/73	73-6.0	10203.1	6216.9	1962.8
7/22/73	73-8.0	9119.7	7788.6	1896.6
7/22/73	73-10.0	8069.0	9669.4	1845.8
7/22/73	73-12.0	7461.5	11638.2	1772.7
7/21/73	73-38.0	32535.9	11221.4	958.3

Table 15, continued

Date	Target	Coordinate X	Coordinate Y	Coordinate Z
3/21/76	A1	20856.3	13095.3	1347.9
3/21/76	A2	20824.6	12982.7	1338.7
3/21/76	A3	20842.9	13045.8	1344.8
3/21/76	A4	20763.1	12840.4	1342.7
3/21/76	A5	20746.9	12799.4	1342.4
3/21/76	A6	20730.2	12754.3	1343.3
3/21/76	A7	20715.3	12717.2	1344.8
3/21/76	A8	20697.2	12664.3	1344.7
3/21/76	A9	20652.2	12544.5	1344.3
3/22/76	A10	20675.5	12608.1	1344.3
3/22/76	A9-A	20652.7	12545.2	1344.2
3/22/76	A11	20624.4	12470.4	1345.9
3/22/76	A12	20594.3	12390.4	1348.6
3/22/76	A13	20625.2	12267.5	1347.8
3/22/76	A15	20656.7	12191.7	1349.0
3/22/76	A14	20670.1	12111.3	1349.9
3/22/76	A16	20610.2	11988.5	1348.7
3/22/76	A17	20581.6	11922.1	1343.4
3/22/76	A18	20514.8	11855.2	1339.1
3/23/76	A20	20118.3	11121.1	1357.8
3/23/76	A21	20149.6	11177.8	1353.7
3/23/76	A23	20217.7	11386.5	1357.6
3/23/76	A24	20253.7	11482.2	1356.1
3/23/76	A25	20296.8	11596.3	1353.5
3/23/76	DENOSE	20320.5	11656.5	1345.1
3/23/76	B1	28918.4	10873.4	1098.4
3/23/76	B2	28894.6	10738.9	1095.1
3/23/76	B3	28876.6	10637.7	1098.8
3/23/76	B4	28862.9	10562.5	1094.9
3/23/76	B5	28842.2	10453.3	1091.3
3/23/76	B6	28822.3	10349.6	1090.1
3/23/76	B7	28803.5	10249.8	1097.1
3/23/76	B8	28786.3	10151.3	1100.6
3/23/76	B9	28768.7	10061.5	1109.6

Table 16. Altimeter altitude measurements made on August 27, 1970

[Locations refer to centerline coordinates (table 21, later in the report) and were determined by map reading. Locations are accurate to about 200 meters. km, kilometers; m.a.s.l., meters above sea level]

Location (km)	Altitude (m.a.s.l.)
3.6	2,044
8.9	1,861
13.0	1,747
19.0	1,546
25.6	1,345
32.0	1,144
36.8	1,020
41.0	896

Table 17. Ice thickness, Black Rapids Glacier

[Thickness profiles are plotted in figure 10. The coordinates for the shot location (X, Y, and Z) are reported in the local coordinate system. All thicknesses were measured using ice penetrating radar systems. Some shots had two returns; the second return is marked with an asterisk (*). Ice radar measurement positions that were not surveyed were estimated either by map reading (labeled: map est.) or compass and tape measure "surveys" (labeled: taped est.)]

Date	Shot	Profile	Delay time (micro-seconds)	Antenna separation (meters)	Return radius (meters)	Shot location coordinate X	Y	Z	Position surveyed or estimated
3/21/76	3	25.9 km	2.1	115	197	20840	13039	1339	Surveyed
3/21/76	4	25.9 km	2.2	45	199	20834	13014	1342	Surveyed
3/21/76	4*	25.9 km	2.5	45	221	20834	13014	1342	Surveyed
3/21/76	6	25.9 km	3.2	44	283	20755	12820	1343	Surveyed
3/21/76	7	25.9 km	3.4	48	301	20739	12777	1343	Surveyed
3/21/76	8	25.9 km	3.5	40	308	20723	12736	1344	Surveyed
3/21/76	10	25.9 km	3.9	56	346	20706	12691	1345	Surveyed
3/21/76	12	25.9 km	8.7	128	762	20675	12604	1345	Surveyed
3/22/76	15	25.9 km	4.7	67	411	20664	12576	1344	Surveyed
3/22/76	18	25.9 km	5.2	80	453	20638	12507	1345	Surveyed
3/22/76	19	25.9 km	5.1	86	446	20609	12430	1347	Surveyed
3/22/76	19*	25.9 km	5.2	86	462	20609	12430	1347	Surveyed
3/22/76	22	25.9 km	5.8	99	512	20610	12329	1348	Surveyed
3/22/76	23	25.9 km	6.0	102	528	20648	12189	1349	Surveyed
3/22/76	24	25.9 km	5.2	54	447	20663	12151	1349	Surveyed
3/22/76	25	25.9 km	6.3	128	560	20640	12050	1349	Surveyed
3/22/76	26	25.9 km	6.2	190	565	20626	12017	1347	Surveyed
3/22/76	27	25.9 km	6.5	62	565	20596	11955	1346	Surveyed
3/22/76	29	25.9 km	5.0	80	436	20571	11915	1343	Surveyed
3/23/76	31	25.9 km	0.7	110	73	20150	11123	1354	Surveyed
3/23/76	33	25.9 km	1.1	109	114	20218	11442	1358	Surveyed
3/23/76	36	25.9 km	1.8	102	176	20236	11434	1357	Surveyed
3/23/76	38	25.9 km	2.5	137	234	20275	11539	1355	Surveyed
3/23/76	41	25.9 km	3.1	147	292	20309	11626	1349	Surveyed
3/23/76	43	34.4 km	3.6	137	338	28907	10806	1097	Surveyed
3/23/76	44	34.4 km	3.3	103	303	28886	10688	1097	Surveyed
3/23/76	44*	34.4 km	3.7	103	338	28886	10688	1097	Surveyed
3/23/76	46	34.4 km	4.6	76	407	28870	10600	1097	Surveyed
3/23/76	47	34.4 km	5.3	111	473	28853	10508	1093	Surveyed
3/23/76	48	34.4 km	5.3	105	467	28832	10401	1091	Surveyed
3/23/76	49	34.4 km	4.7	102	424	28813	10300	1094	Surveyed
3/23/76	50	34.4 km	2.6	100	243	28795	10201	1099	Surveyed
3/23/76	51	34.4 km	3.9	92	352	28778	10106	1105	Surveyed

Table 17. Ice thickness: Black Rapids Glacier **--continued**

Date	Shot	Profile	Delay time (micro-seconds)	Antenna separation (meters)	Return radius (meters)	Shot location coordinate X	Y	Z	Position surveyed or estimated
5/23/90	S5	15 km	1.9	55	173	9459	12218	1719	Surveyed
5/23/90	S4	15 km	4.5	55	392	9466	12515	1705	Surveyed
5/23/90	S3	15 km	6.6	55	569	9472	12754	1704	Surveyed
5/23/90	S2	15 km	6.5	55	561	9488	13027	1704	Surveyed
5/23/90	S1	15 km	5.1	55	443	9504	13284	1703	Surveyed
5/23/90	WE	15 km	3.9	55	342	9531	13585	1700	Surveyed
5/23/90	N1	15 km	3.0	55	266	9533	13821	1697	Surveyed
5/23/90	N2	15 km	2.0	55	181	9535	13997	1694	Surveyed
5/23/90	N3	15 km	1.5	55	139	9536	14164	1690	Surveyed
5/23/90	S2	14 km	7.0	55	603	8782	13526	no data	Taped est.
5/23/90	S1	14 km	6.2	55	535	8782	13326	no data	Taped est.
5/23/90	14 km site	14 km	5.4	55	468	8782	13126	1725	Surveyed
5/23/90	N1	14 km	4.9	55	426	8782	12946	no data	Taped est.
5/23/90	N2	14 km	3.1	55	274	8782	12766	no data	Taped est.
5/26/90	S3	20 km	1.7	55	156	14785	12814	no data	Taped est.
5/26/90	S2	20 km	3.0	55	266	14785	13014	no data	Taped est.
5/26/90	S1	20 km	5.2	55	451	14785	13214	no data	Taped est.
5/26/90	20 km site	20 km	6.4	55	552	14785	13414	1516	Surveyed
5/26/90	N1	20 km	6.0	55	519	14785	13614	no data	Taped est.
5/26/90	N2	20 km	5.8	55	502	14785	13814	no data	Taped est.
4/22/87	40km	Terminus	2.4	60	216	33948	12208	844	Map est.
4/22/87	39km	Terminus	3.4	60	301	33120	11646	872	Map est.
4/22/87	38km	Terminus	3.8	60	330	32311	11058	896	Map est.
4/22/87	37km	Terminus	4.3	60	377	31458	10535	930	Map est.
4/22/87	36km	Terminus	4.5	60	394	30478	10332	964	Map est.
4/22/87	35km	Terminus	4.8	60	415	29842	10238	1004	Map est.
4/22/87	33.5km	Terminus	5.2	60	453	28006	10504	1057	Map est.
4/22/87	32km	Terminus	4.7	60	411	26542	10831	1109	Map est.
3/27/79	4km	Point shots	4.0	100	357	11224	4750	2028	Surveyed
3/28/79	8km	Point shots	7.5	50	644	9074	8123	1894	Surveyed
3/18/78	14km	Point shots	5.6	46	483	8877	13142	1713	Surveyed
3/18/78	20km	Point shots	6.7	58	578	14790	13402	1513	Surveyed
3/20/78	26km	Point shots	6.0	126	531	20433	12225	1342	Surveyed

Table 18. Local coordinates of monuments used for geodetic surveys, Black Rapids Glacier

Monument name	Coordinate (meters)			Monument name	Coordinate (meters)		
	X	Y	Z		X	Y	Z
The End	12055.96	1734.10	2481.80	**Lake**	14557.92	14664.43	1606.81
Torque	11726.18	2029.96	2485.99	**Soaked**	16918.58	14852.46	1609.27
Adrenaline	13215.73	3519.86	2483.35	**Blank**	16854.23	11871.79	1566.44
Perfect	8881.37	5938.20	2023.48	**Blue**	19093.73	14205.48	1510.77
Ozone	10793.10	7260.12	2049.86	**Devil**	18756.53	10142.25	1930.40
Smoke	10809.68	7274.03	2058.11	**Eagle**	21101.92	10581.78	1625.24
Red	7517.13	8012.09	2003.81	**Erratic**	23396.99	12904.72	1394.22
Green	7525.94	8021.07	1999.87	**All Wrong**	26207.33	9242.37	1627.76
Fireweed	7522.75	8024.68	2003.80	**Denali**	28033.91	13303.18	1916.89
Rotten	5935.54	10923.66	1998.65	**Rubble**	30163.10	8696.27	1549.25
Potholes	4959.20	12811.29	1925.65	**Disaster**	30610.19	11654.74	1201.59
Rainbow	6599.03	14875.82	1861.03	**Hook**	31647.94	12002.22	1113.01
No Return	9849.30	11927.90	1804.87	**Crook**	31676.76	11976.84	1106.12
Willsear	8618.91	14595.73	1834.18	**O'Damnit**	32846.13	9871.75	1299.47
Wills Left Ear	8566.45	14839.10	1869.64	**Flop**	33653.93	13189.10	1139.44
Calcite	11908.03	14488.58	1666.71	**1937**	36222.48	13268.10	955.06
Shudder	12326.47	12248.34	1690.99				

Table 19. GPS-derived coordinates for Lake and Potholes monuments.
[GPS survey to top of monuments, in North American Datum 1927 (NAD27). Local coordinate was converted to UTM, then into the local system using equations 1 and 2. GPS, Global Positioning System; h, ellipsoid height]

Monument	GPS-derived position			Local coordinate (meters)	
	Latitude	Longitude	h		
	(decimal degrees)		(meters)	X	Y
Lake	63.494457	146.388807	1625.03	14440.10	14635.39
Potholes	63.478584	146.581736	1944.62	4841.13	12788.72

Table 20. Additional points surveyed in both the GPS derived coordinate system and the local coordinate system

[These points help serve as a check on the network shift based on the GPS surveys. Note that the stakes were displaced by ice motion in the period between surveys. GPS, Global Positioning System]

Target	GPS derived position		GPS derived local coordinate			Geodetically surveyed local coordinate		
	Latitude	Longitude	Date	X	Y	Date	X	Y
	(decimal degrees)			(meters)			(meters)	
8 km stake	63.436607	146.500457	9 May 92	9050.37	8163.58	4 May 92	9051.52	8162.64
14 km stake	63.481361	146.504979	9 May 92	8782.78	13150.82	4 May 92	8781.97	13150.46
20 km stake	63.483151	146.384453	9 May 92	14787.86	13406.33	5 May 92	14786.87	13406.41

Table 21. Centerline coordinate system, Black Rapids Glacier

[km, kilometers]

Site (km)	Coordinate (meters)		Site (km)	Coordinate (meters)		Site (km)	Coordinate (meters)	
	X	Y		X	Y		X	Y
0	13455.1	1450.6	24	18760.6	12699.1	48	40025.6	17277.6
1	12905.9	2286.7	25	19733.4	12465.6	49	40334.8	18229.1
2	12317.9	3096.0	26	20698.3	12201.6	50	40178.3	19217.1
3	11742.7	3914.5	27	21667.3	11952.9	51	39869.1	20168.5
4	11193.4	4750.6	28	22640.0	11719.3	52	39635.6	21141.3
5	10618.2	5569.1	29	23612.7	11485.8			
6	10069.0	6405.2	30	24589.0	11267.6			
7	9546.3	7258.2	31	25565.3	11049.3			
8	9064.3	8134.8	32	26541.6	10831.1			
9	8555.1	8995.9	33	27517.9	10612.9			
10	8129.2	9901.0	34	28494.2	10394.7			
11	7746.3	10825.3	35	29482.3	10238.2			
12	7512.8	11798.0	36	30478.2	10332.3			
13	7952.9	12696.4	37	31457.8	10535.2			
14	8844.3	13150.5	38	32310.8	11057.9			
15	9832.3	13307.0	39	33120.1	11645.9			
16	10830.7	13369.9	40	33947.5	12208.2			
17	11829.1	13432.6	41	34676.7	12893.0			
18	12829.5	13432.6	42	35314.4	13663.8			
19	13829.9	13432.6	43	35976.0	14414.2			
20	14829.8	13401.2	44	36794.4	14989.4			
21	15827.1	13322.7	45	37663.4	15485.1			
22	16815.2	13166.2	46	38554.7	15939.2			
23	17787.9	12932.7	47	39364.1	16527.2			

Loket Tributary

Site (km)	Coordinate X	Coordinate Y
26	20698.3	12201.6
L-25	19697.9	12201.7
L-24	18725.2	11968.1
L-23	17880.5	11432.1
L-22	17398.6	10555.5
L-21	17242.1	9567.4
L-20	16787.9	8676.0
L-19	16419.7	7745.9
L-18	16576.2	6757.8
L-17	16576.2	5757.5
L-16	16497.7	4760.2
L-15	17085.7	3950.8
L-14	17977.0	3496.7
L-13	18901.3	3113.8
L-12	19874.0	2880.3

APPENDIX A

Terminus Motion During the 1936-37 Surge

Appendix A. Terminus motion during the 1936-37 surge

Hance (1937) estimated that the terminus of Black Rapids Glacier advanced approximately 3 miles between September 1936 and February 1937, giving an average speed of 115 feet per day. Dr. Otto Geist's (University of Alaska) observations near the end of the advance are reported below. We have one of the few (perhaps only) known copies of Geist's data and present it here to preserve it. A description of the field work was written by Giddings (1988), a member of Geist's field party.

The locations of Geist's observations along the surge front are recorded on a map. The map is not reproduced here due to problems with the control and scale. The approximate distance of the observation lines measured from the south ice margin along the surge front is: Line 1: 750 m, line 3A: 1200 m, line 4: 1400 m, line 4A: 1450 m, line 5: 1850 m, line 6, 2000 m, and the north ice margin: 2350 m.

Table A1. Geist's observations of the 1937 terminus advance, Black Rapids Glacier

Advance (feet)	Date	Time	Speed (feet per day)	
			From first observation	Between measurements
Line Number 1				
0	02-Apr-1937	11:32		
4	02-Apr-1937	15:50	22.3	22.3
7	02-Apr-1937	18:55	22.8	23.4
25	03-Apr-1937	11:00	25.6	26.9
29	03-Apr-1937	14:42	25.6	25.9
34	03-Apr-1937	18:14	26.6	34.0
35	03-Apr-1937	19:40	26.1	16.7
47	04-Apr-1937	08:05	25.3	23.2
55	04-Apr-1937	15:22	25.5	26.4
59	04-Apr-1937	19:00	25.5	26.4
79	05-Apr-1937	06:50	28.2	40.6
80	05-Apr-1937	13:40	25.9	3.5
83	05-Apr-1937	19:00	25.1	13.5
100	06-Apr-1937	08:00	26.0	31.4
115	07-Apr-1937	18:00	21.8	10.6
153	08-Apr-1937	16:50	24.6	39.9
Line Number 2				
0	02-Apr-1937	12:00		
4	02-Apr-1937	15:46	25.5	25.5
6	02-Apr-1937	18:45	21.3	16.1
26	03-Apr-1937	11:05	27.0	29.4
29	03-Apr-1937	14:40	26.1	20.1
35	03-Apr-1937	19:40	26.5	28.8
50	04-Apr-1937	08:40	26.9	27.7
59	04-Apr-1937	15:25	27.5	32.0
64	04-Apr-1937	19:00	27.9	33.5
77	05-Apr-1937	06:55	27.6	26.2
82	05-Apr-1937	14:00	26.6	16.9
85	05-Apr-1937	18:55	25.9	14.6
95	06-Apr-1937	08:00	24.8	18.3
112	06-Apr-1937	18:00	26.4	40.8
136	07-Apr-1937	15:40	26.4	26.6
168	08-Apr-1937	17:40	26.9	29.5

Table A1. Geist's observations of the 1937 terminus advance, Black Rapids Glacier, **continued**

Advance (feet)	Date	Time	Speed (feet/day)	
			From first observation	Between measurements
Line Number 3				
0	04-Apr-1937	14:45		
23	05-Apr-1937	07:55	32.2	32.2
35	05-Apr-1937	18:34	30.2	27.0
52	06-Apr-1937	08:30	29.9	29.3
92	07-Apr-1937	15:46	30.2	30.7
130	08-Apr-1937	17:50	31.5	35.0
179	10-Apr-1937	10:05	30.8	29.2
Line Number 3A				
0	05-Apr-1937	14:47		
4	05-Apr-1937	18:30	25.8	25.8
19	06-Apr-1937	20:40	15.3	13.8
Line Number 4				
0	04-Apr-1937	11:08		
50	05-Apr-1937	12:40	47.0	47.0
55	05-Apr-1937	18:20	42.3	21.2
97	06-Apr-1937	08:40	51.1	70.3
151	07-Apr-1937	15:58	47.2	41.4
164	08-Apr-1937	18:05	38.2	11.9
Line Number 4A				
0	02-Apr-1937	17:10		
1	02-Apr-1937	18:30	18.0	18.0
38	05-Apr-1937	12:30	13.5	13.5
42	05-Apr-1937	18:10	13.8	16.9
51	06-Apr-1937	08:50	14.0	14.7
79	07-Apr-1937	16:10	15.9	21.4
102	08-Apr-1937	18:15	16.9	21.2
137	10-Apr-1937	10:00	17.8	21.1
Line Number 5				
0	04-Apr-1937	14:10		
1	05-Apr-1937	12:00	1.1	1.1
21	05-Apr-1937	18:05	18.1	78.9
29	06-Apr-1937	09:00	16.2	12.9
62	07-Apr-1937	16:15	20.1	25.3
82	08-Apr-1937	18:25	19.6	18.3
132	10-Apr-1937	10:00	22.7	30.3
Line Number 6				
0	04-Apr-1937	13:55		
20	05-Apr-1937	12.15	21.5	21.5
25	05-Apr-1937	17:55	21.4	21.2
39	06-Apr-1937	09:10	21.6	22.0
78	07-Apr-1937	16:25	25.1	30.0
100	08-Apr-1937	18:30	23.9	20.2
145	10-Apr-1937	09.45	24.9	27.5

APPENDIX B

Data Disk Information

Appendix B. Data Disk Information

A data disk is included with this report. The disk contains the mass balance, ice velocity, surface altitude, and ice thickness data tables. It is a 3.5-inch, 1.44 megabyte disk formatted with IBM PC operating system MS-DOS 6.0. Data tables are written to it in two formats: ASCII text and Lotus 123 version 2.01 .WK1 spreadsheet format. The ASCII files are in a subdirectory named *ASCII* and the Lotus 123 files are in a subdirectory named *lotus123*.

In the root directory on the disk there is an ASCII file named README.TXT. It says:

```
This text file contains an overview of the files available on
this data disk.

Report title:
Observations of the Surge-Type Black Rapids Glacier, Alaska,
   During a Quiescent Period, 1970-92
by TA Heinrichs, LR Mayo, DC Trabant, and RS March, 1995
US Geological Survey Open File Report 94-512

For additional information write to:
District Chief
US Geological Survey
4230 University Drive, Suite 201
Anchorage, Alaska, 99508-4664

This disk contains the mass balance, ice velocity, surface
altitude, and ice thickness data tables. It is a 3.5-inch, 1.44
megabyte disk formatted with IBM PC operating system MS-DOS 6.0.
Data tables are written to it in two formats: ASCII text and
Lotus 123 version 2.01 .WK1 spreadsheet format. The ASCII files
are in a subdirectory named "ASCII" and the Lotus 123 files are
in a subdirectory named "LOTUS123".

The following tables are on this disk. Listed below are the Lotus
123 file names with .WK1 extension. The ASCII text files have the
same names, except the file name extension is .TXT. For example,
Table 1 is TABLE1.TXT

Table #   File name      Table description
-------   ---------      --------------------------------
1         TABLE1.WK1     Net mass balance (summary)
9A        TABLE9A.WK1    Ice velocity data 2 km site
9B        TABLE9B.WK1    Ice velocity data 4 km site
9C        TABLE9C.WK1    Ice velocity data 8 km site
9D        TABLE9D.WK1    Ice velocity data 14 km site
9E        TABLE9E.WK1    Ice velocity data 20 km site
9F        TABLE9F.WK1    Ice velocity data 26 km site
9G        TABLE9G.WK1    Ice velocity data 32 km site
9H        TABLE9H.WK1    Ice velocity data 38 km site
9I        TABLE9I.WK1    Ice velocity data L-19 km site
9J        TABLE9J.WK1    Ice velocity data L-22 km site
10        TABLE10.WK1    Additional ice velocity measurements
```

11	TABLE11.WK1	Longitudinal velocity profile (7/73 to 7/74)
12	TABLE12.WK1	Velocity cross-profiles
14A	TABLE14A.WK1	Surface altitude 2 km site
14B	TABLE14B.WK1	Surface altitude 4 km site
14C	TABLE14C.WK1	Surface altitude 8 km site
14D	TABLE14D.WK1	Surface altitude 14 km site
14E	TABLE14E.WK1	Surface altitude 20 km site
14F	TABLE14F.WK1	Surface altitude 26 km site
14G	TABLE14G.WK1	Surface altitude 32 km site
14H	TABLE14H.WK1	Surface altitude 38 km site
14I	TABLE14I.WK1	Surface altitude L-19 km site
14J	TABLE14J.WK1	Surface altitude L-22 km site
15	TABLE15.WK1	Extensive surface altitude surveys (1973 & 1976)
17	TABLE17.WK1	Ice thickness
18	TABLE18.WK1	Local coordinates of geodetic control monuments
21	TABLE21.WK1	Centerline coordinate system

APPENDIX C

Area-Altitude Distribution

Table C1. Area-altitude distribution of Black Rapids Glacier

[The area-altitude distribution was measured from figure 2 by laying a dot grid over map and counting the number of dots between contours.]

Altitude (meters)		Area (square kilometers)		Percentage debris-covered ice
From	To	Total	Debris-covered ice	
800	900	5.69	5.19	91.2
900	1000	4.31	2.38	55.1
1000	1100	5.06	2.31	45.7
1100	1200	9.88	5.00	50.6
1200	1300	8.94	3.44	38.5
1300	1400	9.44	3.63	38.4
1400	1500	12.81	2.75	21.5
1500	1600	13.13	2.31	17.6
1600	1700	20.19	2.13	10.5
1700	1800	28.06	0.44	1.6
1800	1900	33.69	0.06	0.2
1900	2000	36.31	---	---
2000	2100	21.38	---	---
2100	2200	14.56	---	---
2200	2300	9.50	---	---
2300	2400	5.19	---	---
2400	2500	2.44	---	---
2500	2600	1.19	---	---
2600	2700	1.63	---	---
2700	2800	0.88	---	---
2800	2900	0.94	---	---
2900	3000	0.56	---	---
3000	3100	0.44	---	---
3100	3200	0.19	---	---
	Totals	***246.38***	***29.63***	

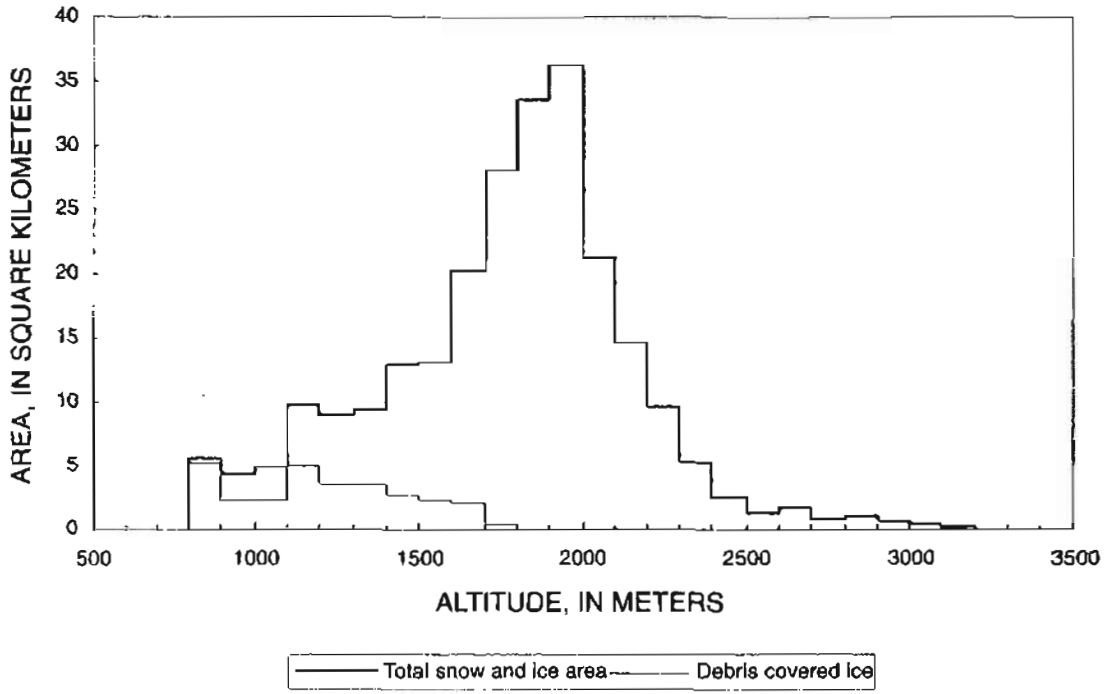

Figure C1. Area-altitude distribution of Black Rapids Glacier, Alaska

Table C2. Area-altitude distribution of all the glacier snow and ice in the Black Rapids Glacier drainage basin

[This table includes all the snow and ice in the drainage basin, including unattached glaciers in tributary valleys. The area-altitude distribution was measured from figure 2 by laying a dot grid over map and counting the number of dots between contours.]

Altitude (meters)		Area (square kilometers)		Percentage debris-covered ice
From	To	Total	Debris-covered ice	
800	900	5.69	5.19	91.2
900	1000	4.31	2.38	55.1
1000	1100	5.44	2.50	46.0
1100	1200	10.31	5.13	49.7
1200	1300	9.75	3.63	37.2
1300	1400	10.56	4.19	39.6
1400	1500	14.63	3.31	22.6
1500	1600	16.50	3.31	20.1
1600	1700	24.63	3.13	12.7
1700	1800	33.06	1.06	3.2
1800	1900	38.44	0.13	0.3
1900	2000	39.50	---	---
2000	2100	23.44	---	---
2100	2200	15.69	---	---
2200	2300	10.31	---	---
2300	2400	5.81	---	---
2400	2500	3.00	---	---
2500	2600	1.56	---	---
2600	2700	1.63	---	---
2700	2800	0.88	---	---
2800	2900	0.94	---	---
2900	3000	0.56	---	---
3000	3100	0.44	---	---
3100	3200	0.19	---	---
	Totals	***277.25***	***33.94***	

APPENDIX D

Snow Pit Data

Appendix D. Snow Pits

Data were gathered from 23 snow pits on Black Rapids Glacier. Uncertainties in the snow pit density observations are reported below in table D1. The snow pit data are in tables D2-D24. Density was measured by taking vertical core sections from the wall of the pit (fig. 5). The *sample mass* was measured with a spring scale. The *sample depth range* is the top and bottom of the core section. The sample cross-sectional area is listed in the notes section at the bottom of the table. Using the area and the depth range, the volume and *density* of the sample can be calculated. The *average density* for the entire length of core is listed at the bottom of the density column. The *water equivalent* of the core section is calculated by multiplying the relative density [$\rho(s)/\rho(w)$] by the sample length. The total snow balance, $b(s)$, for the core is at the bottom of the snow balance column. The depth at which the temperatures were measured is reported in the right-hand column. *Temperature depth* is measured down from the snow surface. In the "Notes" section, the *summer surface* is identified; the type of material and the observed qualities used to identify it are reported here. The *average snow depth* is the average of the pit depth and the snow probings. Temperatures in the snowpack were measured with calibrated, dial-type thermometers. Accuracy is estimated to be ±1°C.

Table D1. Uncertainties in snow pit density observations
[m, meters; ρ, density; g/cm³, grams per cubic centimeter]

Quantity	Estimated uncertainty	Comments
Individual quantities:		
Sample depth	±0.01 m	
Sample diameter	0.001 m	
Sample mass	10 grams	
Combined:		
Error for each sample	3.6 percent	0.01 g/cm³ for a sample with 0.40 m depth, 0.0723 m diameter, 500 g mass (ρ=0.305 g/cm³); errors combined in quadrature
Error for entire core	$\frac{1}{\sqrt{n}} \times 3.6$ percent	0.005 g/cm³ for a 2 m deep pit (5 samples); *n* is the number of samples in the core

Table D2. Snow pit: 4 km site, 3/27/74, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density	Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)	(m_{we})	Depth (cm)	Value (°C)
0	15	80	0.21	0.03	0	-13.0
15	30	125	.33	.05	10	-13.8
30	45	105	.27	.04	30	-13.8
45	60	135	.35	.05	60	-12.5
60	75	115	.30	.05	100	-11.8
75	90	145	.38	.06	150	-10.3
90	105	115	.30	.05	193	-8.0
105	120	105	.27	.04		
120	135	140	.37	.05		
135	150	135	.35	.05		
150	165	145	.38	.06		
165	180	130	.34	.05		
180	193	110	.33	.04		
		Average:	**.32**	**Total b(s):** **0.62**		

Notes:
Summer surface: dirt at 1.93 m; depth hoar 1.05-1.93 m
Average snow depth: 1.93 m
Sample cross-sectional area: 25.5 cm²

Table D3. Snow pit: 4 km site, 2/28/75, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density	Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)	(m_{we})	Depth (cm)	Value (°C)
0	40	365	0.22	0.09	10	-18.0
40	80	430	.26	.10	30	-15.0
80	120	515	.31	.13	60	-13.8
120	160	610	.37	.15	100	-13.0
160	200	695	.42	.17	150	-12.5
200	240	725	.44	.18	200	-10.0
240	280	785	.48	.19	250	-8.5
280	320	820	.50	.20	300	-7.0
320	350	600	.49	.15	350	-6.0
350	368	310	.42	.08	370	-5.0
		Average:	**.39**	**Total b(s):** **1.43**		

Notes:
Summer surface: dirt layer at 3.68 m; depth hoar 3.50-3.68 m
Average snow depth: 3.76 m
Sample cross-sectional area: 41.05 cm²

Table D4. Snow pit: 8 km site, 8/28/75, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	30	655	0.53		0.16	throughout	0.0
30	54	520	.53		.13		
54	78	470	.48		.11		
		Average:	**.51**	**Total b(s):**	**.40**		

Notes:
Summer surface: heavy dirt layer at 0.78 m
Average snow depth: 0.78 m
Sample cross-sectional area: 41.05 cm²

Table D5. Snow pit: 8 km site, 3/24/76, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	285	0.17		0.07	0	-10.0
40	80	435	.26		.11	10	-12.5
80	120	585	.36		.14	30	-15.3
120	160	655	.40		.16	60	-15.0
160	200	635	.39		.15	100	-13.4
200	250	570	.28		.14	150	-12.0
250	283	660	.49		.16	200	-10.4
						250	-8.4
		Average:	**.33**	**Total b(s):**	**.93**	283	-7.0

Notes:
Summer surface: slightly dirty at 2.83 m; many melt crusts 2.34-2.83 m
Average snow depth: 2.85 m
Sample cross-sectional area: 41.05 cm²

Table D6. Snow pit: 8 km site, 9/13/76, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density	Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)	(m_{we})	Depth (cm)	Value (°C)
0	25	270	0.26	0.07	10	-3.0
25	50	475	.46	.12		
50	80	600	.49	.15		
80	115	765	.53	.19		
		Average:	**.45**	**Total b(s):** **.51**		

Notes:
Summer surface: dirt at 0.25 m--1976 summer surface;
very dirty at 1.15 m--1975 summer surface
Average snow depth: 0.25 m
Sample cross-sectional area: 41.05 cm²

Table D7. Snow pit: 8 km site, 3/19/77, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density	Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)	(m_{we})	Depth (cm)	Value (°C)
0	40	335	0.20	0.08	0	-12.0
40	80	495	.30	.12	10	-17.0
80	120	615	.37	.15	30	-18.0
120	160	645	.39	.16	60	-16.0
160	200	760	.46	.19	100	-12.0
200	240	775	.47	.19	150	-9.5
240	280	765	.47	.19	200	-8.2
280	320	755	.46	.18	250	-7.0
320	357	700	.46	.17	300	-6.0
					357	-5.0
		Average:	**.40**	**Total b(s):** **1.42**		

Notes:
Summer surface: slight dirt at 3.89 m, iced firn below
Average snow depth: 3.87 m
Sample cross-sectional area: 41.05 cm²

Table D8. Snow pit: 8 km site, 8/23/77, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	380	0.23		0.09	0	-0.5
40	82	565	.33		.14	10	-4.0
						30	-2.0
		Average:	**.28**	**Total b(s):**	**.23**	60	-1.0
						82	-0.5

Notes:
Summer surface: dirt at 0.82 m; very hard firn below
Average snow depth: 0.78 m
Sample cross-sectional area: 41.05 cm²

Table D9. Snow pit: 8 km site, 3/22/78, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	325	0.20		0.08	0	-10.5
40	80	565	.34		.14	10	-21.1
80	120	625	.38		.15	30	-16.7
120	160	605	.37		.15	60	-14.0
160	200	715	.44		.17	100	-11.5
200	228	525	.46		.13	150	-10.0
						200	-7.2
		Average:	**.36**	**Total b(s):**	**.82**	226	-6.5

Notes:
Summer surface: medium dirt layer at 2.28 m, refrozen firn below
Average snow depth: 2.28 m
Sample cross-sectional area: 41.05 cm²

Table D10. Snow pit: 8.7 km site, 10/27/73, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	320	0.19		0.08	0	-8.8
40	79	475	.30		.12	10	-12.0
79	103	455	.46		.11	30	-9.2
103	142	790	.49		.19	60	-5.3
						100	-3.0
		Average:	**.35**	**Total b(s):**	**.50**	150	-1.8

Notes:
Summer surface: 1973 summer surface at 0.79 m--dirt layer;
1972 summer surface at 1.03 m--dirt layer;
1971 summer surface at 1.42 m--slight dirt and crystal change
Average snow depth: 0.79 m
Sample cross-sectional area: 41.05 cm²

Table D11. Snow pit: 14 km site, 3/1/75, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	350	0.21		0.09	0	-18.5
40	80	480	.29		.12	10	-19.0
80	120	585	.36		.14	30	-15.5
120	160	625	.38		.15	60	-11.8
160	200	725	.44		.18	100	-10.0
200	214	210	.37		.05	150	-8.0
						200	-7.5
		Average:	**.34**	**Total b(s):**	**.72**	214	-5.5

Notes:
Summer surface: ice
Average snow depth: 2.26 m
Sample cross sectional area: 41.05 cm²

Table D12. Snow pit: 14 km site, 3/28/79, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	315	0.19		0.08	0	-25.0
40	80	470	.29		.11	10	-20.0
80	120	550	.33		.13	30	-14.0
120	160	640	.39		.16	60	-10.5
160	190	515	.42		.13	100	-9.5
190	211	360	.42		.09	150	-8.0
						211	-7.0
		Average:	**.33**	**Total b(s):**	**.69**		

Notes:
Summer surface: ice
Average snow depth: 2.08 m
Sample cross sectional area: 41.05 cm²

Table D13. Snow pit: 14 km site, 3/25/80, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	300	0.18		0.07	10	-15.3
40	80	495	.30		.12	30	-12.3
80	120	545	.33		.13	60	-11.0
120	160	620	.38		.15	100	-10.4
160	200	580	.35		.14	150	-9.2
200	209	180	.49		.04	209	-7.1
		Average:	**.32**	**Total b(s):**	**.66**		

Notes:
Summer surface: ice
Average snow depth: 2.90 m
Sample cross sectional area: 41.05 cm²

Table D14. Snow pit: 14 km site, 4/22/83, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	375	0.23		0.09	0	-0.5
40	80	525	.32		.13	10	-1.5
80	120	680	.41		.17	30	-6.0
120	160	665	.40		.16	60	-7.2
160	205	760	.41		.19	100	-7.2
						150	-6.7
		Average:	**.36**	**Total b(s):**	**.73**	210	-5.5

Notes:
Summer surface: ice
Average snow depth: 2.29 m
Sample cross sectional area: 41.05 cm²

Table D15. Snow pit: 14 km site, 4/4/86, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	385	0.23		0.09	0	-10.5
40	80	525	.32		.13	10	-21.1
80	120	665	.40		.16	30	-16.7
120	160	765	.47		.19	60	-14.0
160	200	620	.38		.15	100	-11.5
200	226	505	.47		.12	150	-10.0
						200	-7.2
		Average:	**.37**	**Total b(s):**	**.84**	226	-6.5

Notes:
Summer surface: ice
Average snow depth: 2.09 m
Sample cross-sectional area: 41.05 cm²

Table D16. Snow pit: 19 km site, 4/3/73, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	475	0.29		0.12	0	0.0
40	80	540	.33		.13	10	-12.0
80	116	505	.34		.12	30	-9.6
						60	-7.6
		Average:	**.32**	**Total b(s):**	**.37**	100	-6.8
						116	-6.8

Notes:
Summer surface: ice
Average snow depth: 1.22 m
Sample cross-sectional area: 41.05 cm²

Table D17. Snow pit: 19 km site, 3/28/74, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	15	100	0.26		0.04	0	-9.6
15	30	115	.30		.05	10	-11.2
30	45	120	.31		.05	30	-11.0
45	60	108	.28		.04	60	-9.4
60	75	120	.31		.05	86	-8.2
75	90	95	.25		.04		
		Average:	**.29**	**Total b(s):**	**.26**		

Notes:
Summer surface: ice
Average snow depth: 0.90 m
Sample cross-sectional area: 25.5 cm²

Table D18. Snow pit: 26 km site, 3/3/75, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	475	0.29		0.12	0	-13.5
40	80	515	.31		.13	10	-15.0
80	121	565	.34		.14	30	-14.0
						60	-10.0
		Average:	**.31**	**Total b(s):**	**.38**	121	-6.5

Notes:
Summer surface: Ice
Average snow depth: 1.59 m
Sample cross-sectional area: 41.05 cm²

Table D19. Snow pit: 32 km site, 4/4/73, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	490	0.30		0.12	0	-5.4
40	83	625	.35		.15	10	-5.2
						30	-6.9
		Average:	**.33**	**Total b(s):**	**.27**	60	-6.8

Notes:
Summer surface: Ice
Average snow depth: 0.67 m
Sample cross-sectional area: 41.05 cm²

Table D20. Snow pit: 32 km site, 3/26/76, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	240	0.15		0.06	0	-16.0
40	80	530	.32		.13	10	-12.0
80	114	495	.35		.12	30	-10.5
						60	-9.5
		Average:	**.27**	**Total b(s):**	**.31**	100	-7.0
						126	-6.0

Notes:
Summer surface: ice
Average snow depth: 1.42 m
Sample cross-sectional area: 41.05 cm²

Table D21. Snow pit: 32 km site, 3/14/77, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	475	0.29		0.12	0	-5.0
40	80	620	.38		.15	10	-9.0
80	120	610	.37		.15	30	-10.0
120	168	735	.37		.18	60	-9.0
						100	-6.0
		Average:	**.35**	**Total b(s):**	**.59**	168	-4.0

Notes:
Summer surface: ice
Average snow depth: 2.05 m
Sample cross-sectional area: 41.05 cm²

Table D22. Snow pit: 32 km site, 4/20/83, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	320	0.19		0.08	0	0.0
40	80	575	.35		.14	10	-2.0
80	120	585	.36		.14	30	-4.0
120	157	600	.40		.15	60	-4.0
						100	-4.0
		Average:	**.32**	**Total b(s):**	**.51**	157	-3.5

Notes:
Summer surface: ice
Average snow depth: 1.63 m
Sample cross-sectional area: 41.05 cm²

Table D23. Snow pit: 32 km site, 3/18/84, Black Rapids Glacier

[See Appendix D text for explanation of methods and terminology. cm, centimeter; g, grams; m_{we}, meters of water equivalent; g/cm³, grams per cubic centimeter; °C, degrees Celsius; cm², square centimeters, m, meters, b(s), snow balance.]

Sample depth range (cm)		Sample mass	Density		Water equivalent	Snow Temperature	
Top	Bottom	(g)	(g/cm³)		(m_{we})	Depth (cm)	Value (°C)
0	40	550	0.33		0.13	0	-12.0
40	80	510	.31		.12	10	-16.0
80	120	505	.31		.12	30	-11.8
120	139	500	.64		.12	60	-8.0
						100	-5.6
		Average:	**.36**	**Total b(s):**	**.50**	139	-5.0

Notes:
Summer surface: ice
Average snow depth: 1.34 m
Sample cross-sectional area: 41.05 cm²

APPENDIX E

Summer Surface Temperature Estimates

Appendix E. Summer surface temperature estimates

The summer surface temperature used to estimate internal accumulation at a site was measured occasionally. However, in most cases it had to be estimated from observations at other sites on Black Rapids Glacier or from unpublished observations at Gulkana Glacier. Gulkana Glacier is 60 km southeast of Black Rapids Glacier (fig. 1) and has been monitored since 1960, which is before the inception of the Black Rapids monitoring program. For some years, unpublished snow pit data from Gulkana Glacier were used to estimate Black Rapids summer surface temperatures. The following summer surface temperature estimation techniques are used: If more than one summer surface temperature was measured at Black Rapids Glacier, the missing values are calculated from a regression line through the data measured there. This technique was used in 1974, 1975, 1976, 1977, and 1983. If only one summer surface temperature was measured at Black Rapids Glacier and two or more measured at Gulkana Glacier, the temperature gradient with altitude calculated with a regression of the Gulkana data is used to extrapolate the single Black Rapids temperature measurement to the altitudes of the observation sites. This was done with data for 1973, 1978, and 1984. If only one summer surface measurement was made at both Black Rapids and Gulkana, then the summer surface temperature measured at Black Rapids is extrapolated in altitude using the average observed gradient at Black Rapids Glacier (0.89 degrees/1,000 m). This was used in 1979, 1980, 1986. If no pits were dug at Black Rapids and only one at Gulkana, the average difference between the two glaciers' summer surface temperature at the same altitude (1.4°C) is used to extrapolate the observed Gulkana temperature to Black Rapids, and the average gradient is used to extrapolate it with altitude (1981, 1982, 1985, 1987, 1988, 1990, 1992.) And finally, if no pits were dug at either glacier, the average of all observed and calculated temperatures at a site is used for the summer surface temperature (1989, 1991).

Table E1. Summer surface temperatures and internal accumulation, Black Rapids Glacier

[The summer surface temperature is used to calculate internal accumulation, b(k). In the "Site" column, the Gulkana Glacier (Alaska, 63° 15' N, 145° 25' W) sites are as follows: Gulkana A is at 1390 meters altitude in the ablation zone. Gukana B is at 1660 meters, near the equilibrium line. Gulkana D is at 1830 meters in the accumulation area. °C, degrees Celsius; —, no data or not applicable.]

Date	Site	Summer surface temperature (°C)		Internal accumulation (meters of water/year)
		Observed	Estimated	
4/03/73	19 km	-6.8	—	—
3/27/74	19 km	-8.2	—	—
	2 km	—	-7.9	0.30
	4 km	-8.0	—	0.31
	8 km	—	-8.1	0.31
2/28/75	14 km	-5.5	—	—
	26 km	-6.5	—	—
	38 km	-6.0	—	—
	4 km	-5.0	-5.2	0.19
	8 km	—	-5.3	0.20
3/24/76	32 km	-6.0	—	—
	4 km	—	-7.2	0.27
	8 km	-7.0	-7.0	0.27
3/19/77	32 km	-4.0	—	—
	2 km	—	-5.4	0.21
	4 km	—	-5.2	0.20
	8 km	-5.0	-5.0	0.19
3/22/78	4 km	—	-6.4	0.24
	8 km	-6.5	-6.5	0.25
3/28/79	14 km	-7.0	—	—
	4 km	—	-7.3	0.28
	8 km	—	-7.2	0.27
3/14/80	14 km	-7.1	—	—
	4 km	—	-7.3	0.28
	8 km	—	-7.2	0.27
	L19 km	—	-6.9	0.27
3/30/81	Gulkana B	-4.2	—	—
	2 km	—	-6.1	0.23
	4 km	—	-5.9	0.23
	8 km	—	-5.8	0.22
	L19 km	—	-5.6	0.21
3/27/82	Gulkana B	-5.0	—	—
	4 km	—	-6.7	0.26
	8 km	—	-6.6	0.25
4/20/83	14 km	-5.5	—	—
	32 km	-3.5	—	—
	4 km	—	-6.5	0.25
	8 km	—	-6.1	0.23
3/18/84	32 km	-5.0	—	—
	4 km	—	-6.5	0.25
	8 km	—	-6.3	0.24

Table E1. Summer surface temperature and internal accumualtion—**continued**

Date	Site	Summer surface temperature (°C)		Internal accumulation (meters of water/year)
		Observed	Estimated	
3/23/85	Gulkana A	-6.5	---	---
	4 km	---	-8.5	0.33
	8 km	---	-8.4	0.32
4/04/86	14 km	-6.9	---	---
	4 km	---	-7.2	0.27
	8 km	---	-7.1	0.27
3/24/87	Gulkana A	-5.6	---	---
	8 km	---	-7.5	0.29
4/16/88	Gulkana B	-4.0	---	---
	8 km	---	-5.9	0.23
4/19/89	8 km	---	---	0.26
5/06/90	Gulkana D	-4.8	---	---
	8 km	---	-6.7	0.26
5/01/91	8 km	---	---	0.26
3/26/92	Gulkana D	-4.6	---	---
	8 km	---	-6.5	0.25